SCHOOL SCIENCE AND MATHEMATICS

Volume 115 • Number 8 • December 2015

SSMA Official Journal of the School Science and Mathema

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School Science and Mathematics (Print ISSN: 0036-6803, Online ISSN: 1949-8594) is published in January, February, March, April, May, October, November and December on behalf of the School Science and Mathematics Association by Wiley Subscription Services, Inc., a Wiley Company, 111 River St., Hoboken, NJ, 07030-5774. Periodical postage paid at Hoboken, NJ and additional offices.

Postmaster: Send all address changes to *School Science and Mathematics*, Journal Customer Services, John Wiley & Sons Inc., C/O The Sheridan Press, PO Box 465, Hanover, PA 17331.

Information for Subscribers: *School Science and Mathematics* is published in eight issues per year. Subscription prices for 2015 are: Institutional Print & Online rate: US$370 (the Americas), US$370 (Rest of World), €267 (Europe) £227 (UK). Prices are exclusive of tax. Asia-Pacific GST, Canadian GST/HST and European VAT will be applied at the appropriate rates. For more information on current tax rates, please go to www.wileyonlinelibrary.com/tax-vat. The price includes online access to the current and all online back files to January 1st 2011, where available. For other pricing options, including access information and terms and conditions, please visit www.wileyonlinelibrary.com/access.

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Production Editor: Chelmin Lim (ssm@wiley.com)

Electronic Access: This journal is available online at *Wiley Online Library*. Visit http://wileyonlinelibrary.com/ to search the articles and register for table of contents and email alerts.

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ISSN: 0036-6803 (Print)
ISSN: 1949-8594 (Online)
Printed in the US by The Sheridan Group.

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Examining the Leaky STEM Talent Pipeline—Need for Further Research

A college education has long been considered the key to the American dream, opening the door to a vista of opportunity and financial prosperity. Data on college access in recent decades indicate that the United States has made significant strides in providing that key to students across the nation. With the establishment of federal programs such as the Pell Grant and TRIO Programs targeted to assist low-income students, it is tempting to conclude that all students, regardless of socioeconomic background, face a level playing field in terms of college access and completion. In reality, although recent years have seen significant improvements in college access for U.S. students as a whole, gains in access continue to lag for low-income students, and those who do enroll in college are consistently less likely than their higher-income peers to secure baccalaureate degrees (Adelman, 2006; Engle & Tinto, 2008; Kena et al., 2015). A recent study conducted by the National Student Clearinghouse Research Center revealed that over the past two decades, over 31 million students enrolled in college without graduating with a degree or certificate. Indeed, for students in the low-income demographic, the world of higher education continues to look less like a ladder to success and more like a revolving door. Along with low-income students in a variety of majors, this *revolving door* continues to displace students who choose science, technology, engineering, and math (STEM) majors, a phenomenon that has implications not only for individual students, but also for the growing income inequality and STEM labor force in our nation.

STEM fields, according to the Bureau of Labor Statistics, fall within two major domains: (a) the science, engineering, mathematics, and information technology domain, including the fields of life sciences, physical sciences, and social sciences; and (b) the science- and engineering-related domain, including the fields of health and architecture (Jones, 2014). Employment in these STEM fields is not only projected to grow faster than the average for all occupations, but the median wage of STEM workers in 2013 was more than double that of other occupations (Vilorio, 2014). These high-paying jobs fulfill a labor force need and represent a path out of poverty for the low-income demographic for students with STEM baccalaureate degrees. In fact, the President's Council of Advisors on Science and Technology identified as a national priority bolstering the number of students earning a STEM undergraduate degree by 34% over 2012 rates (Olson & Riordan, 2012). The focus on increasing the numbers of STEM graduates seems warranted when one considers that, although between 2003 and 2009, 28% of first-year bachelor's degree students declared a STEM major, nearly half of those students eventually left their STEM studies, either by switching majors or leaving college altogether (Chen & Soldner, 2013). This attrition was unevenly divided between income quartiles, however, and between 2003 and 2009, over 29% of STEM majors in the lowest income quartile left college without a degree or certificate compared with only 15% of STEM majors in the highest income quartiles (Chen & Soldner, 2013).

As the plethora of literature on college access, student persistence, and student success suggests, these are complex enterprises, spanning a range of disciplines, from sociology to economics to psychology to education (Perna & Thomas, 2006; Terenzini & Reason, 2005). Students' college experiences are as varied and nuanced as the students themselves, and numerous contextual factors beyond the need for financial support contribute to students' decisions to enroll in and complete college degrees and must be considered in any investigation of student success. Furthermore, although three decades of research helped us identify disproportionate factors contributing to student attrition from the postsecondary pipeline, translating theory into actionable models and effective programs has proved difficult. We still lack scalable models for student access to and persistence while attending college (Tinto, 2007).

It is clear that college access, student persistence, and overall student success (including graduation and placement in the workforce) are arduous challenges in the United States, particularly for economically disadvantaged students in STEM fields. While some entities have

periodically evaluated the programs focused on increasing the talent pool and the number of STEM degree seekers and completers; there has not been a close examination of investments, strategies, and associated impact of on the STEM pipeline in terms of STEM student persistence, retention, completion, and placement into the workforce. Much can be learned from the significant investment that has made on providing access to low-income students from all backgrounds (i.e., ethnic/racial, disability, gender), including examining the academic and career trajectories (i.e., majors/programs, career placement) that students choose, as well as the barriers/challenges they encounter along their educational path.

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Examining Elementary School Science Achievement Gaps Using an Organizational and Leadership Perspective

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There is the tendency to explain away successful urban schools as indicative of the heroic efforts by a tireless individual, effectively blaming schools that underperform for a lack of grit and dedication. This study reports the development of a research instrument (School Science Infrastructure, or SSI) and then applying that tool to an investigation of equitable science performance by elementary schools. Our efforts to develop a science-specific instrument to explore associations between school-level variables and equitable science performance are informed by James Coleman's tripartite notion of social capital: the "wealth" of organizations is encompassed within their social norms, informational channels, and reciprocating relationships. Grounded in school effectiveness research and social capital theory, the instrument that we report on here is a valid and reliable tool to support meso-level investigations of factors contributing to school variations in science achievement.

The persistence of science achievement disparities is not an intractable problem. Even when populated by similar students, certain schools overcome the "demographics is destiny" stereotype. Unfortunately, there is the tendency to explain away successful urban schools as indicative of the heroic efforts by a tireless individual (Tough, 2008)—effectively blaming schools that underperform for a lack of grit and dedication. In contrast, empirical studies of school effectiveness demonstrate how math and reading achievement gaps are narrower in schools displaying particular organizational and leadership structures (Bryk, Sebring, Allensworth, Luppescu, & Easton, 2010). From our vantage point, educational equity reforms, including those specific to science, solely focused on classroom interventions will falter if contextual factors are ignored (Ladson-Billings, 2006). Just as Petty, Wang, and Harbaugh (2013) reported in this journal how schoolwide characteristics are related to mathematics achievement, the current study used the school as the level of analysis with the goal of identifying causes of—and potential solutions to—science achievement gaps (National Center for Educational Statistics [NCES, 2011]). A crucial step toward realizing this goal is to develop techniques for studying school-level aspects of science education. Here we report on the development of an instrument to assess infrastructures associated with elementary school science and demonstrate how it can be applied to address pressing questions about equity in science education.

Background

The controversy about school effects on student learning can be traced to the legendary 1966 Coleman Report. In that document, family and neighborhood factors were shown to be substantially more influential on children's learning than did anything transpiring within the school (Coleman, 1968). Those findings prompted considerable educational reform ranging from school desegregation via busing to countless studies of linkages between school practices and learning outcomes (Cuban, 1984; Viadero, 2006). Bifurcated beliefs about causes for uneven student achievement continue to be debated. A commonly endorsed view is that learning is largely a psychological process: children acquire knowledge and skills supplied by their classroom teacher and the instructional materials (Allen et al., 2013). The associated logic is that differences in achievement between children can be attributed to student aptitude and teacher talents. Research on science learning by and large endorses this notion. Most science education research about student cognition concentrates on individual mental activity despite widespread

acceptance of social constructivist theory. Resistance to the growing evidence that organizational features shape children's science learning belies a psychological parochialism. Piagetian views associated with Sputnik-era reform maintain a grip on science education researchers despite evidence that canonical views (e.g., developmental stage theory) do not withstand empirical analyses (Metz, 1995). A more accurate perspective about learning is that students jointly construct meanings even as broader background factors shape what youngsters are able to achieve (Bransford, Brown, & Cocking, 1999). Consequently, achievement differences can be attributed to factors that transcend the individual.

Anyone who has taught science recognizes how the work environment, the surrounding community, and the interactions among people influence efforts to support student learning. Research has repeatedly demonstrated how school organization and leadership affect student achievement (Hallinger & Heck, 2011; Wahlstrom & Louis, 2008). However, science education researchers seem resistant to the notion that context matters by instead choosing to primarily conduct research on the interplay between a teacher and his or her students, with little attention paid to contextual factors that exert subtle yet substantial influences. A hasty dismissal of organizational influences on students' science learning is not only shortsighted but could undermine efforts to reduce science achievement gaps (NCES, 2011).

None of this is meant to suggest that the quality of teaching is inconsequential—far from it (Nye, Konstantopoulos, & Hedges, 2004). Given the multiple culprits for inequitable education (i.e., poverty rates, uneven distribution of educational resources, imbalances in the availability of quality teachers, inadequate supplies of quality curriculum, and the variability in learning environments), it is reasonable that science educators would focus on areas where they are most familiar and comfortable (Darling-Hammond, 2010). When achievement disparities are acknowledged, attention is typically directed at teacher preparation, professional development, and curriculum refinements. Neglected is the sizable evidence that school structure and leadership practices—the ecology of a school and the coordination of that system—have demonstrable impacts on students' academic performance (Leithwood, Harris, & Hopkins, 2008). Unfortunately, when school effectiveness research is conducted, almost invariably it is restricted to the heavily tested subjects of reading and math (Bryk et al., 2010), with few studies about the contextual impacts on science achievement (Fraser & Kahle, 2007; Wood, Lawrenz, Huffman, & Schultz, 2006).

If we are genuinely concerned that schools are perpetuating discriminatory practices, a claim advanced specifically for science education (Schmidt & McKnight, 2012), then we must be open to an array of transgressing agents. Resolving achievement disparities necessarily requires attending to the wide range of contributing variables—from instructional strategies to curriculum materials to out-of-school influences (Evans, 2005; Milner, 2012; Rodriguez, 2001). One challenge is that, even with the availability of student science test scores, to date school effectiveness studies of science education have been hampered by the absence of science-sensitive instrumentation. Because school leadership and organizational structures have content-specific features (Spillane, 2005), additional research tools are needed. This article reports on the development of such an instrument that can then be applied to the investigation of associations between school-level factors and equitable science performance.

School Organization and Leadership

Although few studies examine connections between science learning and school effectiveness, considerable research has revealed strong statistical relationships between school contexts and student achievement in reading and math (Coelli & Green, 2012; Leithwood, Patten, & Jantzi, 2010). School organization and building-level leadership would be reasonably expected to influence science achievement just as has been discovered for math and reading. However, this line of investigation is full of challenges, given the complexities of distinguishing student features from broader school-level factors. Poverty serves as a prime example of this conundrum. At a micro-level, a child living in poverty would be expected to have more difficulty in science classes than a child who lives in a nonimpoverished home. Being poor imposes challenges in the form of insecurities: uncertain supplies of nutritious food, transiency/homelessness, and the associated psychological and developmental diminutions (Ransdell, 2012). In contrast, a meso-level consideration of poverty affects schoolwide achievement as measured by the proportion of low-income children enrolled (NCES, 2010). This distinction is equivalent to comparing cellular activity with ecological processes. Rather than concentrating on what transpires in one classroom, we emphasize the likelihood that schools as organizational systems and the leadership exerted within those settings produce observable and substantial influence on student science outcomes.

Schools as Organizations

Researchers who value schoolwide influences on student achievement have noted the importance of parental involvement, an orderly atmosphere, an achievement-oriented climate, and staff cohesiveness (Scheerens, 2001). Van de Grift and Houtveen (2006) found moderate effect sizes for organizational features that distinguished improving schools: teacher collaboration, faculty meetings centered on educational quality, and supportive school climate. In addition, leadership in the form of administrative support and encouragement of the faculty correlated with significant achievement growth. In contrast to beliefs about schools' weak impacts relative to family and community inputs, such studies reveal how schools enhance students' academic performance.

Multiple school-level factors are consistently shown to be viable contributors to not only improved student achievement but also reduced inequities in test performance. Among the contributing factors are organizational trust (Cosner, 2009), professional capacity (Bryk et al., 2010), and social networks (Penuel, Riel, Krause, & Frank, 2009)—especially the influence of leaders within the school (Hallinger & Heck, 2011; Wahlstrom & Louis, 2008). The sizable impact that schoolwide factors can have on equitable test performance resonates with recent re-analyses of the Coleman Report's data (Konstantopoulos & Borman, 2011). Numerous school effectiveness studies confirm linkages between organizational characteristics of a school and the achievement of students (Supovitz, Sirinides, & May, 2010). However, despite a host of proposed organizational models (e.g., Griffith, 2003) the field has yet to identify a theoretical framework that adequately accounts for these findings (Scheerens, 2013).

Leadership Within a School

Within an ecological, school-level perspective, the organization can be thought of as the structure, while leadership practices serve to coordinate the system. Principals have myriad responsibilities that include school building operations (scheduling, space management), financial oversight (budgets, grants), personnel duties (supervising, hiring), instructional guidance (teaching evaluations, professional development), internal coordination (faculty cohesiveness), and external relationships (family partnerships, corporate sponsors) (May, Huff, & Goldring, 2012). When the time a principal spends on various tasks is examined in light of improved test performance, intriguing patterns arise (Horng, Klasik, & Loeb, 2010). Principals who devote more time to coaching teachers, developing the educational program, and conducting teacher evaluations are leading schools that show significant improvements over time in student math test scores (Grissom, Loeb, & Master, 2013). Interestingly, the frequent practice of instructional walk-throughs (City, Elmore, Fiarman, & Teitel, 2009) revealed negative associations with achievement growth, and none of the factors related to math achievement were significant for reading achievement (Grissom et al., 2013).

Leadership takes many forms with "distributed leadership" having received considerable attention (Spillane & Healey, 2010). Looking beyond the principal and administrative team, leadership extends to others who guide, direct, and influence a school's educational programs. This elevates the importance of considering the utility of teacher-leaders (York-Barr & Duke, 2004) along with the possibility that science leadership requires special actions distinct from leadership for other subjects—perhaps even more so when leading science in culturally and linguistically diverse settings (Scanlan & López, 2012; Stein & Nelson, 2003). Therefore, when investigating leadership's potential impacts on student science achievement, all who contribute to leading the school need to be taken into account. Paralleling Hiebert and Morris (2012) who recommend a focus on teaching instead of just the teachers, this study considers leading rather than simply the school leaders.

Theoretical Framework: Social Capital

Our efforts to develop a science-specific instrument to explore associations between school-level variables and equitable science performance were informed by James Coleman's (1988) tripartite notion of social capital: the "wealth" of organizations is encompassed within their social norms, informational channels, and reciprocating relationships (Dika & Singh, 2002)—all of which are shaped by the leadership exerted within the school. Thus, the capacity of a school to react to demands placed on it and its resiliency to perturbations reflect the supply of social capital (Holme & Rangel, 2012). Social capital offers a useful ecological perspective (cf. Scholz & Reydon, 2008) contrasting with a school capacity or human capital paradigm (Odden, 2011). Smylie and Evans (2006) posit that using social capital as a theoretical lens allows educational researchers to examine relationships in organizational structures that may support or impede educational change. Toward these ends, we sought to capture the "investments" schools make in children's educational futures through schoolwide efforts at fostering organizational trust, maintaining group norms, and preserving

communication networks (Daly, Moolenaar, Der-Martirosian, & Liou, 2014). In this regard, this study was grounded in Coleman's social capital theory with the goal of better understanding the influences on achievement by elementary school students (Kahlenberg, 2001).

With social capital as our underlying theory, we present a two-part study of school-level factors and student science achievement. First, we describe the development of the School Science Infrastructure (SSI) survey that promises to be a tool for capturing teacher perceptions of schoolwide factors. Second, we describe a foray into assessing the tool's utility by comparing teachers' responses to the SSI with student performance on the annual statewide science test. The study was guided by two research questions corresponding to the overall structure of this article, namely:

1. What does the SSI capture about teachers' views of organizational and leadership structures and practices, particularly in regard to science learning and student diversity?
2. What associations exist between SSI factors and school performance on a statewide science test after accounting for student demographics?

SSI Instrument: Development Process

The development of the SSI followed a very deliberate process involving 18 months of effort consisting of distinct phases (Table 1). First, a deliberately broad list of categories and items was generated, starting with an organizational report on Chicago elementary schools (Bryk et al., 2010) along with an exhaustive search of the research literature. For example, we elaborated on "school climate" (to include emphasis on academics, students' sense of safety, and maintenance of order), "professional capacity" (to encompass professional development, deprivatized practices, and faculty commitment to the school), and "school leadership" (to incorporate instructional, administrative, distributed functions along with commitments to equity). The initial pool consisted of nearly 200 items dispersed across 18 categories as presented in Table 2.

Table 1
Summary of the SSI Development Process

Phase	Purpose	Participants	Results
1	Initial item pool	Research team	200 items across 18 categories
2	Content validation	13 Science educators	Reduction of items to just under 100
3	Teacher validation	131 K–8 teachers	Refinement of items for phrasing and structure
4	Pilot test #2	504 K–8 teachers nationally	EFA suggests 9 factors for 67 items
5	Pilot test #3	~700 K–8 CT and FL teachers	CFA leading to 64-item SSI

Because of the highly varied ways in which science instruction is provided in elementary school, many teachers are not directly engaged with helping children to learn science (Banilower et al., 2013). With the school as the unit of analysis, it was important to assess schoolwide factors without eliminating those adults who do not teach science. Teachers not formally assigned to teach science would nonetheless be aware of the emphasis of science within the school's larger mission. Rather than exclude such perceptions, the items were developed without presuming a respondent was responsible for providing science instruction. Since the survey itself focused on schoolwide science programming, many items transcend the particulars of science teaching in favor of capturing broader essences of science education throughout the building. Even though many SSI items did not specifically include the word "science," respondents likely recognized its implied presence across all survey prompts.

An expert content panel of 13 individuals was recruited from among science education researchers, classroom teachers, school administrators, and district science coordinators (e.g., via the National Science Education Leadership Association). Filtered through their expertise, the panelists conducted a content analysis: sorting each item into the category that it best seemed to belong, indicating the confidence with which they placed the item in that category, and then indicating the degree of alignment between the item and the category definition. This information was used to modify the prompts while simultaneously reducing the number of items.

The subsequent pilot test with 131 kindergarten through eighth grade (K–8) teachers surfaced additional issues, prompting revision of the SSI. In particular, the pattern of responses revealed that items proffering uncomplimentary views of others clustered as a separate factor. In response, negatively worded items were revised or deleted. Other items for which there were inconsistent responses were eliminated, leading to a revised survey that served as the basis for subsequent field testing.

A national marketing company that maintains panels of educators for research studies was contracted to supply 500+ K–8 teachers to participate in the next content

Table 2
Initial Pool of Items

A. Leadership within the School	
Intellectual and instructional leadership	The school leadership identifies science goals, supports development of science teaching expertise, and displays expertise about supporting science instruction.
Coordinating processes and distributing responsibilities	The school leader creates collaborative opportunities, maintaining lines of communication, and encouraging involvement in decision-making.
Administrative management	The school leader effectively manages the budgetary, scheduling, staffing, and material needs associated with the operation of the school.
Leadership promoting commitments to equity	The school leader acknowledges educational inequities and encourages efforts to reduce the associated inequities.
B. School Climate	
Emphasis on academics	The schools focus on strengthening students' understandings of subject matter.
Students' sense of safety	Students feel protected, appreciated, and successful within this school.
Maintaining safety and order	Efforts by adults to ensure that the school is welcoming, orderly, and safe.
C. Professional Capacity	
Professional development	The impact of professional development on the recipients.
Deprivatized practice	Forms of collaboration with colleagues to advance science teaching practices.
Commitment to the school	Satisfaction with and commitment to being a teacher at one's current school.
D. Ties Among Teacher/Family/Community	
Teacher direct agency	Teachers communicate with families about events taking place in the classroom.
Teacher proxy agency	Teachers partner with families to extend curriculum-related activities into the home.
Teacher collective agency	Teachers incorporate community resources into instruction to advance student learning.
Community support services	Familiarity with social supports that could provide services to children and families.
E. Trust (in Other Teachers, in the Principal, or with the School Community)	
Competence	Other teachers within the school (or the principal) possess necessary expertise to capably carry out responsibilities, have a reasonable professional repertoire, and are adept at selecting from and applying those in their work.
Integrity	Other teachers (or the principal) exhibit consistency between words and deeds, statements, and actions, and this consistency provides the assurance that one's individual needs will be met and justice will be upheld.
Personal regard	The teacher is cared about and valued by other teachers (or the principal). Relationships reflect mutual goodwill with the expectation that one's well-being will be protected rather than exploited.
Openness	The school community operates with transparency in terms of information and explanations, policies and decision-making, operations, actions, and behaviors.

Table 3
Descriptive Statistics from Confirmatory Factor Analysis (n = 661)

Factor	# of Items	Cronbach's Alpha	Inter-Item Correlates: Mean (SD)
1. Principal Dependability	16	.97	.72 (.170)
2. Collaborative Teacher Learning in Science	9	.88	.45 (.110)
3. Other Teachers' Trustworthiness	11	.90	.46 (.080)
4. Social Service Knowledge	4	.88	.65 (.056)
5. Families as Educational Partners	4	.80	.50 (.126)
6. Teacher Pride and Orderly Environment	7	.90	.55 (.122)
7. Principal Advocacy for Equity	4	.83	.56 (.179)
8. Supports for Science Teaching	5	.90	.65 (.114)
9. Shared Decision-Making	4	.82	.54 (.055)

SD, standard deviation.

analysis. Item responses by this population were examined using Exploratory Factor Analysis to uncover whether responses coalesced into distinct categories. Bryk et al. (2010) claimed "five essential supports" that determine which urban elementary schools are capable of supporting student success in language arts and mathematics. We maintained a more objective stance by relying on participants' responses to identify categories. Many items had to be discarded because they failed to aggregate into factors. The result was a manageable 67 items grouped into nine different factors.

We conducted a confirmatory factor analysis (CFA) using responses from nearly 700 practicing K-8 teachers across four metropolitan school systems from Connecticut and Florida. The result was a 64-item survey that measures teacher perceptions about their schools' organizational structures and leadership practices. This iterative and evidentiary process reflects the desire to situate the instrument in the larger body of research while ensuring that the survey was valid and reliable.

SSI Instrument: Analysis and Results

To determine an appropriate number of factors to extract, we examined participant responses via a parallel analysis, the minimum average partial procedure, the scree plot, and the magnitudes of the eigenvalues. Taking all of this into consideration, a nine-factor solution provided the best solution for the data. After further revisions to the items and collecting data from a fresh pool of teachers, we conducted a CFA using Mplus 7. Because the items were measured on a 5-point Likert scale, we treated the response variables as ordinal and computed weighted least square parameter estimates using a diagonal weight matrix with mean and variance adjusted chi-square statistics that use a full weight matrix (Muthén & Muthén, 2013). The results of the CFA indicated that the nine-factor model for the SSI instrument provided an adequate fit to the data (Tables 3, 4, and 5).

Table 4
Means and Standard Deviations within Factor Subscales, Teacher Level

Factor	Mean Response	Standard Deviation	*n*
1. Principal Dependability	4.17	.99	697
2. Collaborative Teacher Learning in Science	3.40	.83	690
3. Other Teachers' Trustworthiness	4.24	.62	692
4. Social Service Knowledge	3.15	1.15	690
5. Families as Educational Partners	2.85	.95	692
6. Teacher Pride and Orderly Environment	4.16	.84	694
7. Principal Advocacy for Equity	4.33	.83	694
8. Supports for Science Teaching	3.60	1.01	692
9. Shared Decision-Making	3.78	.98	694

Table 5
Means and Standard Deviations within Factor Subscales, School Level

Factor	Mean Response	Standard Deviation	*n*
1. Principal Dependability	4.07	.61	23
2. Collaborative Teacher Learning in Science	3.11	.38	23
3. Other Teachers' Trustworthiness	4.17	.27	23
4. Social Service Knowledge	3.10	.37	23
5. Families as Educational Partners	2.77	.54	23
6. Teacher Pride and Orderly Environment	3.99	.50	23
7. Principal Advocacy for Equity	4.25	.50	23
8. Supports for Science Teaching	3.32	.59	23
9. Shared Decision-Making	3.52	.53	23

The resulting nine factors consisted of between 4 and 16 items with correlations among factors ranging from .21 to .93, with the highest correlation between Principal Dependability and Principal Advocacy for Equity.

Table 6
Correlations Among Nine Factors in the SSI

	#1	#2	#3	#4	#5	#6	#7	#8	#9
#1	1.00								
#2	.47	1.00							
#3	.49	.61	1.00						
#4	.21	.42	.36	1.00					
#5	.34	.47	.41	.23	1.00				
#6	.82	.61	.70	.34	.62	1.00			
#7	.93	.46	.54	.21	.35	.76	1.00		
#8	.81	.75	.60	.40	.49	.76	.83	1.00	
#9	.84	.68	.63	.37	.44	.77	.84	.86	1.00

Although conceptually the correlation between Principal Dependability factor and the Principal Advocacy for Equity factor should be strong, the statistics hinted at potential discriminant validity issues. We conducted a second factor analysis that combined the responses of these two factors resulting in an eight-factor model. The corrected chi-square test indicated that the nine-factor solution provided a better fit to the model than did the eight-factor solution (chi-square = 82.79 with 8 degrees of freedom). The scores on the nine scales exhibited adequate internal consistency with Cronbach's alphas ranging from .80 to .97. Correlations among the nine factors are presented in Table 6.

The first research question implied a degree of hesitation about whether survey items could assess elementary school teachers' views of organizational structures and leadership practices within their workplace, with a particular emphasis on science learning and student diversity. The findings offer a resounding confirmation that the SSI captures school-level features about school infrastructure. As with other instruments grounded in social capital theory, the SSI captures both the relationships among educators within the school as well as networks between the school and external groups (Holme & Rangel, 2012; Scanlan & López, 2012). These variants of organizational trust have commonly been described within social capital theory as "bonding" for within institution relationships (e.g., among the teachers) versus "bridging" for cross-institutional associations (e.g., between the school faculty and social service agency) (Nooteboom, 2007). A distinct advance of the SSI over other measures is the attention given to science-specific features of a school. This includes items specific to the principal's leadership in science and the extent of teacher collaborations around science.

Two rounds of factor analysis confirmed that the teacher responses aggregated into nine distinct factors. Further, the nine factors resonated with the three aspects of social capital proposed by Coleman (1988). More than affirming social capital theory's usefulness, the analyses brought to the surface sources of controversy within school effectiveness research (Scheurich, Goddard, Skrla, McKenzie, & Youngs, 2011). For example, while "trust" is typically portrayed as infused throughout schools (Bryk & Schneider, 2002), the data demonstrate that trust is not a unitary force but instead takes various forms (Mayer, Davis, & Schoorman, 1995). The Principal Dependability and Other Teachers' Trustworthiness each captured "trust" with response patterns distinct from one another (Smetana, Wenner, Settlage, & McCoach, 2015). Similarly, rather than a one-dimensional view of leadership, teachers hold a multifaceted perspectives about the roles of the building principal: the managerial aspects of their principal's job (within Principal Dependability) were in a category distinct from instructional leadership (from Supports for Science Teaching), both of which were statistically distinct from Principal Advocacy for Equity. Thus, elementary school teachers conceptualize schools as multidimensional and view leadership as more nuanced than simply the role played by someone holding the title of principal.

SSI and Science Test Scores: Statistical Setup

To explore the potential utility of the SSI, we investigated statistical relationships between teachers' SSI responses and students' science achievement. The sample for the multilevel analyses consisted of 314 K–8 teachers from 28 Connecticut schools. Rather than use raw science test scores, we wanted to quantify school performance in a way that acknowledges the schools' student demographics. Multiple regression made this possible by generating a measure called the "residual." A school's science residual indicates the degree to which students under- or overperformed statistical expectations while accounting for student demographics. A positive residual indicates that a school performed better than statistical projections would have predicted given who attends the school. Similarly, a negative residual reveals that a school performed at a lower level than expected relative to all schools in the state. To compute school science residuals, we built a multiple regression model using school-level demographic variables associated with groups underrepresented in college science majors and postsecondary scientific careers: percent of Black students, percent of Latino students, percent of children from families whose incomes qualify them for free/reduced price lunch (FRPL), and the percent of English language learners (ELLs). We also created quadratic and interaction terms for all of the

Table 7
Variance Components and Inter-Item Correlations (N = 314)

Factor	Between-School Variance	Within-School Variance	Intra-Class Correlation
1. Principal Dependability	.247	.87	.22
2. Collaborative Teacher Learning in Science	.117	.63	.16
3. Other Teachers' Trustworthiness	.054	.32	.14
4. Social Service Knowledge	.067	1.30	.05
5. Families as Educational Partners	.232	.64	.27
6. Teacher Pride and Orderly Environment	.183	.59	.24
7. Principal Advocacy for Equity	.162	.56	.23
8. Supports for Science Teaching	.276	.87	.24
9. Shared Decision-Making	.184	.89	.17

Table 8
Percent Reduction in Between-School Variance with Science Residuals

Factor	Between-School Variance Model 1	Between-School Variance Model 2	Reduction in Between-School Variance
1. Principal Dependability	.247	.18	27.9%
2. Collaborative Teacher Learning in Science	.117	.08	27.7%
3. Other Teachers' Trustworthiness	.054	.05	0%
4. Social Service Knowledge	.067	.06	7.5%
5. Families as Educational Partners	.232	.16	29.6%
6. Teacher Pride and Orderly Environment	.183	.08	54.9%
7. Principal Advocacy for Equity	.162	.14	15.4%
8. Supports for Science Teaching	.276	.19	29.6%
9. Shared Decision-Making	.184	.13	27.7%

independent variables and included them in the regression model. The statistically significant predictors of school science achievement were: (a) the percent of FRPL students, (b) the percent of ELLs, (c) the squared percent of ELLs in the school, and (d) the squared percent of black students in the school. This model explained 81% of the variance in school science achievement.

SSI and Science Test Scores: Results

After running a baseline empty model to estimate the proportion of within- and between-school variance for each of the nine SSI factors, we estimated a multilevel model in which the school-level science residual predicted teachers' scores on each of the nine subscales. One notable finding was that the intra-class correlation coefficients (ICCs) indicated that 15–25% of the variances in SSI subscale scores were between schools on eight of the nine subscales (Table 7). The notable exception was Social Services Knowledge: the ICC for this subscale (.05) was quite low. One hypothesis for this low coefficient is that the four items associated with this subscale fall beyond the realms of school organization and leadership and could have contributed to the weak correlations to the other eight SSI factors. This raises concerns when interpreting results associated with this factor. However, the magnitude of ICCs for the other eight subscales indicates that teachers who are clustered within schools are more similar to each other than they are to teachers in different schools. Schools as a whole do differ from each other in terms of the nine factors measured with SSI. Consequently, the SSI survey distinguished between schools while revealing similarities in perceptions by teachers within their individual schools.

Results from the multilevel analyses revealed that school science residual scores could predict factor scores on six of the nine subscales. Table 8 displays the proportion reduction for between-school variance after adding the science residual score to the multilevel model. Adding the science residual explained 54.9% of the between-school variance in the Teacher Pride and Orderly Environment subscale, and it explained at least 20% of the between-school variance in five of the other subscales. Simply stated: School performance on the statewide science test predicted teachers' perceptions of organization and leadership factors across six SSI subscales.

Discussion

This study builds on prior work in other subject areas showing that the practices by school leaders and the organizational structures of a school have significant influences on student achievement (Wahlstrom & Louis, 2008). To date, the potentially unique aspects of science education have received little attention within studies of school organization and leadership. The presence of "achievement gaps" (i.e., otherwise similarly populated schools producing varied science test results) along with indications that disparities associated with student ethnicities result from complex dynamic processes (Mickelson, 2003) provoked the need for a conceptual shift in our framing of elementary science education. School effectiveness research has demonstrated strong associations between school-level factors and student academic performance in math and reading (Hallinger & Heck, 2011). Rather than be lured into the belief that successful schools in urban environments are a consequence of super-heroic leaders (York-Barr & Duke, 2004) we adopted a more expansive view that gave due consideration to the school as an ecological organization (March & Simon, 1993).

Grounded in school effectiveness research and social capital theory, the instrument reported upon here is a valid and reliable tool supportive of meso-level investigations of school factors contributing to variability in science achievement. While we began with a sizable pool of items, the combination of expert content validation and a series of field tests resulted in a compact and robust instrument. In regard to the first research question, the 64-Likert scale items of the SSI generated scores for nine statistically distinct factors. For the second research question, when SSI responses by teachers within a single state were compared to school science residuals, we found that multiple SSI factors (but not all) were significantly related. While this is not definitive given the restricted scope of the study, it nonetheless suggests that the SSI is a useful tool for supporting further studies of school effectiveness specific to science achievement.

The SSI instrument is grounded in social capital theory (Coleman, 1988) and constituted by three interrelated features: reciprocating relationships, informational channels, and organizational norms. Reciprocating relationships are measured via Principal Dependability and Other Teachers Trustworthiness. Informational channels appear within Collaborative Teacher Learning (e.g., feedback from peers and idea sharing), Principal Advocacy for Equity (e.g., messaging and advocating), and Collaborative Teacher Learning in Science (via coaching, meeting, planning, etc.). Finally, organizational norms reside within Shared Decision Making, Families as Educational Partners, and Teacher Pride and Orderly Environment. That Social Services Knowledge does not clearly fit within any of the three forms of social capital could explain its poor showing relative to the other SSI factors. Still under consideration is a compelling mechanism through which social capital promotes more equitable science achievement. Potential explanations range from social capital as a commodity that collectively enriches the organization (Spillane, Kim, & Frank, 2012) to the possibility that social capital supports organizational alignment (Penuel et al., 2010). In short, the SSI reveals itself to be a reliable tool for studying science at the school-level—questions linger about the exact mechanisms through which social capital enhances student science performance.

The next phase of research will expand upon the work reported here to include a variety of qualitative approaches as well as examining teacher advice networks (Lee, 2014). As with any research tool or methodology, there are cautionary limitations, foremost of which is that the data provided via the SSI are teacher anonymous self-reports. In addition, there are reasonable concerns about representing the complexities of schools using quantitative descriptions. However, when used to complement qualitative examinations of a school, the SSI provides a useful metric. At this stage, the use of the SSI has been restricted to teachers working with students in pre-high school settings. We suspect that in schools departmentalized by subject matter, the organizational dynamics might produce different results. Furthermore, the development of the instrument focused solely on teachers in the United States and would benefit by being applied in other countries. We perceive these as important next steps for the SSI and nominate these as questions deserving of continued pursuit. In the meantime, our research continues to benefit from Coleman's (1988) view that educational institutions are responsible for supporting children's achievement rather than placing blame for underachievement on failures alleged to be rooted in biological, community, ethnic, or familial shortcomings. Finally, we remain optimistic that adopting an ecological perspective toward school science, informed by using the SSI to measure organizational and leadership factors, we can subsequently devise interventions to assist with reducing the science achievement disparities that have been heretofore resistant to change.

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Authors' Note

This material is based upon work supported by the National Science Foundation under NSF Grant Numbers 1338512 and 1119349/59. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

Keywords: school effectiveness, science education, reform, school leadership, equity, climate and culture.

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A Multi-Method Investigation of Mathematics Motivation for Elementary Age Students

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This paper presents the results of a multi-method study examining elementary students with high self-reported levels of mathematics motivation. Second- through fifth-grade students at a Title One school in the southeastern United States completed the Elementary Mathematics Motivation Instrument (EMMI), which examines levels of mathematics motivation across three subscales: (a) Math Anxiety, (b) Self-Efficacy, and (c) Value of Math. Results from this quantitative phase were used to identify a sample for a qualitative phase examining how students who report high levels of motivation perceive mathematics. The resulting qualitative phase utilized a phenomenological design to explore mathematics motivation for a particular set of students in a fifth-grade setting. Findings indicate that elementary students with high mathematics motivation value mathematics as a present and future oriented discipline and value teachers that deemphasize testing as a measure of success.

Motivation has been identified as a factor that is essential for elementary students to be successful when engaging in mathematical tasks. Positive student perceptions regarding the ability to solve mathematical tasks, as well as the value of these tasks, are necessary to support student understanding of mathematical concepts (National Research Council [NRC], 2001). Research indicates that beliefs about mathematics are developed early in life and that once established, are difficult to change. If students display low levels of motivation for mathematics at a young age, these perceptions of ability and value are likely to remain constant as they continue through their academic career (Gottfried, Marcoulides, Gottfried, Oliver, & Guerin, 2007). The relationship between motivation and achievement and the need to establish positive dispositions at an early age provide a rationale to examine factors that may influence mathematics motivation for students in elementary grades.

The present study explores characteristics of high motivation in children from kindergarten through fifth grade. A sequential, multi-method design was utilized to answer two central research questions: How do highly motivated elementary mathematics students describe and experience mathematics and how can teachers support student motivation for mathematics? The overall purpose of the study was to identify student, teacher, and classroom factors that have the potential to influence motivation in a positive manner in an effort to move toward developing a motivation framework in elementary mathematics.

Student Motivation and Mathematics

A wealth of literature supports the significance of motivation on performance and various affective factors for students. Motivation has the potential to predict student performance (Murayama, Pekrun, Lichtenfeld, & vom Hofe, 2013), self-regulation, and effective goal setting (Crede & Kuncel, 2008), persistence (Tulis & Fulmer, 2013), as well as other positive predictors of student learning (Federici & Skaalvik, 2013). Several theories have been developed to examine student motivation such as the expectancy–value model that stresses the importance of goals and value in making decisions. Using this model, researchers posit that self-beliefs and task-beliefs have a reciprocal influence on choices (Eccles, 2011).

In addition, the expectancy–value model has shown that an increase in motivation can also increase the amount of attention and energy directed toward activities that can positively impact student learning (Eccles & Wigfield, 2002). Expectancy-value theory posits that motivation is a function of an individual's expectancy for success for a given task and the individual's value for the task (Eccles & Wigfield, 2002). This theory grew from the early work of Atkinson (1957) and was developed throughout the 1960s and 1970s (Battle, 1965; Crandall, 1969) and is recently associated with the work of Eccles and Wigfield (2002). Within this model, expectancies for success and task value are the two primary constructs related to an individual's motivation. Interestingly, these constructs have been studied together and in isolation; research indicates that task value is often predictive of an individual's choices or

decisions while expectancies for success are more predictive of performance (Wigfield & Eccles, 2002).

Increased motivation can support student persistence through difficult tasks and continue to challenge them in a particular content area. Bandura (1997) discussed the significance of risk taking and persisting in his theory of self-efficacy; he noted that self-efficacy can be predictive of an individual's motivation, affect, and behavior. In fact, Bandura (1997) postulated that students' self-efficacy for a domain may be a better predictor for their achievement in that specific content area than objective assessments. For example, students who are efficacious about their ability to learn mathematics are more likely to attempt challenging tasks, persist at those tasks, and make positive attributions for both success and failure (Bandura, 1989, 1997). The opposite is true of students with low self-efficacy for learning mathematics.

Other theories of motivation, such as self-determination theory, have been used to predict motivation outcome variables like investment in learning activities (Kasser & Ryan, 1996), persistence, and level of achievement (Reeve, Deci, & Ryan, 2004). By incorporating various theories of motivation, a more comprehensive framework for motivation can be put forward. This study builds on the theories of expectancy–value and self-efficacy, in addition to considering math anxiety, which has been linked to motivation in prior research (e.g., Zakaria & Nordin, 2008), in order to formulate a theoretical framework for mathematics motivation.

Although a motivation framework lays out a lens for examining student motivation, it is important to also consider how motivation is linked to what is occurring in the classroom. Students who display high levels of motivation often use critical thinking skills when problem solving and more sophisticated metacognitive strategies for retaining and utilizing new information (Pintrich & Schunk, 2002). The connection between motivation and students' specific strategies for learning highlights the importance of investigating motivation toward mathematics separately from other content areas. Previous research indicates that motivation is context specific and that mathematics motivation is connected to mathematics achievement (Wigfield & Eccles, 1994).

Motivation can be predictive of study skills and student engagement, which positively correlate with mathematics achievement (DiPerna, Volpe, & Elliott, 2005). Student factors such as self-efficacy, anxiety, and task value have also been related to student academic performance (Shores & Shannon, 2007). In addition, these factors have influenced student regulatory strategies, both adaptive and maladaptive, while learning mathematics (Cleary & Chen, 2009). Finally, research indicates that motivation can have an impact on student participation in a mathematics classroom (Jansen, 2008). These studies support the significance of student motivation in a mathematics classroom, providing evidence that motivation is a critical construct with ultimate connections to student achievement in mathematics. However, previous research has tended to examine the implications of motivation rather than provide guidance as to characteristics or methods that may lead to an increase in student motivation for mathematics.

Instructional Practices and Motivation

The National Council of Teachers of Mathematics (NCTM, 2014) recognized the necessity for motivational strategies to be included in the instructional practices of teachers. As NCTM stated, teachers' goals are to "ensure that all students become confident" (NCTM, 2014, p. 109) and "promote positive dispositions toward the student of mathematics" (NCTM, 2014, p. 114–115). The teacher's role was made even more explicit by Pintrich (2003) when he summarized five subscales from existing motivation literature that had direct implications for the design of instructional practices to motivate students: (a) "adaptive self-efficacy and competence beliefs," (b) "adaptive attributions and control beliefs," (c) "higher levels of interest," (d) "higher levels of value," and (e) "goals" (Pintrich, 2003, p. 672).

Research focusing on using instructional technology is one way that motivation has been related to instructional practice. Positive correlations have been found between classroom instructional technologies and student motivation in upper elementary students (Torff & Tirotta, 2010). However, these effects were found to be dependent on the teachers' support and beliefs about technology. This finding supports evidence from other research that teacher beliefs impact components of student motivation such as mastery and performance goals (Muis & Foy, 2010). Muis and Foy (2010) concluded that further research needed to involve not only observing classroom instruction but also interviewing teachers and students to better understand the complex nature of investigating these affective relationships. There is a need for additional research to further explore *how* instructional practices influence students' motivation and achievement (Byrnes & Wasik, 2009). Further, there is substantial evidence that motivation is not generalizable to all students and that considering other external factors might be necessary when examining students' motivation (Murphy et al., 2010).

By further investigating how students describe their experiences with mathematics, researchers might be better able to understand students' motivation and connections to instructional practices and teacher factors. In the current study, we examine factors contributing to the formation of student mathematics motivation, particularly high motivation. By sampling elementary students who report high levels of motivation, we are able to isolate and examine the external and internal factors contributing to these results and therefore begin to make sense of how to positively affect student motivation in mathematics.

Methods

The central research questions guiding this study were (a) How do highly motivated elementary mathematics students describe and experience mathematics and (b) How can teachers support student motivation for mathematics? For the purposes of this study, the research team focused on characteristics of highly motivated students rather than examining low levels of motivation. There is already an abundance of research identifying motivational risk factors, such as mathematics anxiety, instructional practice, and parental influence. The intent was to determine how teachers can capitalize upon or encourage characteristics of highly motivated students in their own mathematics instruction. The research questions were examined using a multi-method design where quantitative data were collected and used to inform the sampling approach for a subsequent qualitative investigation of student perceptions about mathematics motivation.

Participants

Participants in Phase One were second- through fifth-grade students (N = 288) in 16 classes at a Title One magnet elementary school, with an emphasis on mathematics and science education, located in the southeastern region of the United States. The research team chose this school because of the diversity of students, the magnet emphasis, and because the curriculum and instructional practice of the majority of teachers reflected progressive practices in mathematics (NCTM, 2014) as determined through classroom observations and prior work with student teachers in the setting. These characteristics were important because the intent of the study was to identify a variety of students with high levels of mathematics motivation. The research team hypothesized that the use of effective instruction in mathematics could potentially impact student motivation.

The research team used the survey results from Phase One to recruit participants for Phase Two. The research team originally intended to sample highly motivated students from every participating grade level. However, results from Phase One showed higher levels of motivation for all students at the fifth-grade level. These findings were particularly interesting because research suggests students' motivation levels decline as they progress through elementary grades and into middle grades (Pajares, Britner, & Valiante, 2000). The research team wanted to further explore why fifth-grade students in this setting were displaying such high levels of mathematics motivation. Therefore, the original sampling plan was dynamically adjusted to focus on these highly motivated students at the fifth-grade level (n = 20).

Instrumentation

The Elementary Mathematics Motivation Inventory (EMMI) is a 17-item self-report instrument that was developed to measure motivational constructs in children. Items contained positively or negatively phrased statements of disposition toward math, prompting students to respond with a four-point Likert-type scale; "just like me (4)," "sort of like me (3)," "not really like me (2)," and "definitely not like me (1)." Items in the instrument were written to prompt student judgments related to (a) anxiety (Shipman & Shipman, 1985), (b) interest (Hidi & Anderson, 1992), (c) task value (Wigfield & Eccles, 2002), (d) self-efficacy (Bandura, 1997), and (e) goal orientation (Elliott, McGregor, & Gable, 1999). The survey was determined to have a Flesch–Kincaid reading level of 3.1. The following subscales are represented within the EMMI: (a) Math Anxiety, (b) Self-Efficacy, and (c) Value of Math. In a validation study (N = 1,018), the EMMI scale showed high reliability, with Cronbach's alpha at .833 for the 17-item scale and average Cronbach's alpha of .812 for the three subscales (Linder & Smart, 2010).

Phase One

Phase One examined levels of student motivation in mathematics across the elementary grades. This quantitative phase utilized a survey design, in which elementary students (n = 288) completed the EMMI (Linder & Smart, 2010), to identify a sample of students who reported high levels of motivation for mathematics. The three-member research team administered the surveys in person by visiting all second- through fifth-grade classrooms over a two-day period in spring of 2010. Survey items were read aloud to participants in all grade levels to control for reading ability. The teacher remained present during survey implementation to alleviate student testing fears and to assist students who required extra aid.

Data were collected for participant selection purposes; therefore analyses were limited to comparisons of levels of motivation. The researchers first computed the reliability

Table 1
Semi-Structured Interview Protocol

Participants:	Date:	Time:

Questions

1. Do you enjoy math? Follow-up: Why/Why not?
   If yes: Is math a subject that you have always enjoyed or have you recently begun to enjoy it?
2. Do you feel like you are good at math? Follow-up: What makes you feel that way?
3. Do you think that math is important? Follow-up: Why do you think this?
   If clarification is needed: How does math impact your life or the lives of people you know? Will you use math in the future? How?
4. Describe a typical math lesson. Follow-ups: What do you do as a student? What does your teacher do? What do you like about math lessons? What do you dislike about math lessons? Describe how you would change lessons to make them more enjoyable.
5. What do you do when you have a difficult problem or question in math? Follow ups: If you don't understand something in math class, what do you do? How do you feel when you get a problem wrong in math class?
6. Does your teacher think that math is important? Follow-up: How do you know?
7. Can you describe your math teacher for me? Follow-ups: What are your favorite things about your math teacher? Can you give me an example? What are some things you wish you could change about your math teacher? Can you give me an example?
8. Do you feel comfortable asking your teacher for help in math? Follow-up: Why/Why not? What does she do that makes you feel that way?
9. How do you feel about the way your teacher talks to you in math class?
10. If you have something important to say, will your math teacher listen to you?
    Follow-up: How does that make you feel about math? How does that make you feel about your teacher?

coefficient to establish the internal consistency of the overall survey instrument and then again for each of the three motivational subscales identified through principle components factor analysis in a previous validation study (Math Anxiety, Self-efficacy, and Value of Math) (Linder & Smart, 2010). Following this examination, the researchers conducted *t*-tests and examined descriptive statistics for all participants to determine if their responses were significantly different than the midpoint on the EMMI scale (34.5). Next, the research team used analyses of variance (ANOVAs) to compare levels of motivation established from the overall scale for students in different grade levels and with different teachers. This was followed by an investigation of the three subscales within the EMMI scale by conducting multivariate (MANOVAs) to examine the relationships between these subscales and the two units of analysis (grade level and teacher). Finally, because fifth-grade students emerged as highly motivated and the research team made the decision to focus on this group in Phase Two rather than sample from grades two through five, the research team examined descriptive statistics to determine which students displayed the highest levels of motivation across classes at the fifth-grade level.

Phase Two

Phase Two of this study explored how students who reported significantly higher levels of motivation experience mathematics. As described above, data collected in Phase One were used to select a sample of participants for Phase Two who reported high motivation in mathematics. Findings from Phase One indicated that students in all fifth-grade classes displayed higher levels of motivation than students in the second, third, and fourth grades. These results are described in more detail below. The research team interviewed a sample of students from each of the fifth-grade classes. More specifically, a total of 20 participants, or approximately 30% of the fifth-grade sample from Phase One, participated in Phase Two. Student descriptions of mathematics were examined through a phenomenological lens (Moustakas, 1994) by conducting semi-structured interviews with participants to understand how they experienced mathematics and then triangulating the interview results with videos of classroom instruction to determine if student perceptions were consistent with established classroom practices.

Interviews were conducted in pairs to increase comfort level in students and to facilitate possible dialogue between students concerning mathematics. A protocol used in each interview is included in Table 1. Each interview lasted approximately 20 to 30 minutes, a typical length for this age group (Seidman, 2006), and was transcribed by a member of the research team. In addition, the research team conducted 12 scheduled classroom visits (three for each of the four classes) where mathematics instruction was observed.

Data were analyzed in a phenomenological fashion (Moustakas, 1994) by identifying initial meaning units in

the interview data and clustering the units in themes occurring across participants. In an effort to increase trustworthiness, the researchers conducted the first round of data analysis individually and then worked together to identify themes related to student motivation. Individual analyses resulting in agreement in over 95% of the meaning units identified across interviews. The research team discussed inconsistencies and came to an overall agreement about each piece of data.

In order to triangulate the student interview data, researchers examined videos and transcripts of mathematics instruction from multiple classroom observations (N = 12). These classroom observations provided another context to examine alignment between students' perceptions of teacher practices in mathematics and actual observed instructional practices. The school of focus used a subject-centered model where teachers in second through fifth grade are specialists in one area of the curriculum. Using a phenomenological approach allows the researcher to determine perceived truths among groups in terms of how they interpret experiences (Moustakas, 1994). If the themes emerging from the interviews were consistent with what was recorded during observations, it is likely that the observations were capturing a representational picture of instructional practice. The research team analyzed the classroom observational data in the same manner as the interview data. The resulting themes were then compared to those emerging from the interview data.

Results

Phase One

Reliability. Reliability for the EMMI in the present study was estimated by computing the Cronbach's alpha for the overall scale (.849). Further, an examination of "Cronbach's Alpha if Item Deleted" suggested that all items should be retained. In addition, the Cronbach's alpha was computed for each of the three subscales previously identified through principal component analysis (PCA): (a) Math Anxiety (.655); (b) Self-Efficacy (.805); and (c) Value of Math (.687). The validation study (Linder & Smart, 2010) of the EMMI instrument yielded higher results for reliability for individual subscales; however, the sample size in that study (N = 1,018) was much higher than the present sample (n = 288). The moderate to high levels of reliability for individual subscales warrant their use in analysis in addition to examining the overall scale.

Frequencies and *t*-tests. *T*-tests were conducted to determine if participants displayed significantly higher levels of motivation than the midpoint of the summative scale and the midpoints of the scale for each subscale (Math Anxiety, Self-efficacy, and Value of Math). The one sample *t*-test for the overall scale indicated that students in this setting agreed with the EMMI items to a significant extent $t(272) = 10.006$, $p < .001$. The effect size d of .98 indicates a large effect. When examining frequencies of student responses, 76% of students across grade levels responded with moderate to high levels of mathematics motivation (ranging from "sort of like me" with a score of 34 to 51 on the summative scale to "just like me" with a score of 51 to 68 on the summative scale) with 49% of these students responding in the high range of mathematics motivation. The one sample *t*-tests for two out of the three subscales were significant: Self-efficacy, $t(281) = 12.968$, $p < .001$ and Value of Math, $t(276) = 16.605$, $p < .001$, with large effect sizes of d of .77 and d of .98, respectively. Frequencies of student responses on items for each of these subscales indicated that 85% of students across grade levels responded with moderate to high levels of motivation in terms of value of mathematics. Of this 85%, 83% responded with high levels of value toward mathematics. Eighty-two percent of students across grade levels responded with moderate to high levels of motivation in terms of self-efficacy. Of this 82%, 63% responded with high levels of self-efficacy toward mathematics. However, only 52% of students responded with moderate to low levels of math anxiety and of this 52%, 65% responded with low levels of math anxiety.

These results indicate that overall, the majority of students in these settings displayed a fairly high level of mathematics motivation, specifically self-efficacy and value of mathematics. When examining frequencies between grade levels, students at the fifth grade level responded with moderate to high levels of motivation at a greater rate (86%) than students in second (68%), third (75%), and fourth (66%) grade. These differences prompted the research team to explore if significant differences occurred between grade levels or individual teachers.

Analysis of variance. One-way analyses of variance were conducted to evaluate the relationship between student motivation for mathematics and each of the following units of analysis: (a) grade level and (b) teacher. The dependent variable for each analysis was the summative score for the overall EMMI scale. There were no significant differences between students at different grade levels or with different teachers when examining the overall scale, so the research team then examined the individual subscales within the EMMI scale.

Multivariate analysis of variance. Following the analysis of the overall EMMI scale, the research team examined each subscale (Math Anxiety, Self-Efficacy, and Value of Math). A series of one-way MANOVAs were conducted to evaluate the relationship between two units of analysis (grade level and teacher) and the three subscales in the EMMI scale. The independent variable for each MANOVA was the unit of focus (grade level or teacher) and the dependent variables were the three subscales. The researchers first conducted MANOVAs to control for the Type I error inflation that could occur from conducting individual analyses of variances (ANOVAs). The alpha for each test was set at .05. Significant differences were identified both between grade levels and between teachers: Grade (Wilks's $\Lambda = .85$, $F[3, 268] = 4.904$, $p < .01$), Teacher (Wilks's $\Lambda = .69$, $F[45, 761] = 2.27$, $p < .01$).The multivariate $\eta 2$ for Grade was .05 and for Teacher was .12, indicating a small effect for each test.

ANOVAs on individual dependent variables were conducted as follow-up tests to the MANOVAs. The alpha for each test was .05. Statistically significant findings are described below.

The ANOVA for *grade level* and *self-efficacy* was significant ($F[3, 270] = 6.80$, $p < .001$). Follow-up tests were conducted to evaluate pairwise differences among the means. Levene's Statistic revealed equal variances, resulting in the use of Bonferroni's post hoc comparison. Fifth grade students reported significantly higher levels of self-efficacy for mathematics than students in second, third, and fourth grades.

The ANOVA for *teacher* and *self-efficacy* was also significant ($F[15, 258] = 3.14$, $p < .001$). In addition, the ANOVA for *teacher* and *math anxiety* was significant ($F[15, 258] = 1.98$, $p < .05$). However, post hoc results did not indicate significant differences among teachers in terms of students' levels of self-efficacy or math anxiety.

Based on these results, students at the fifth-grade level seemed to display higher levels of mathematics motivation, specifically self-efficacy, than students in other grades. The overall high levels and increased frequencies of these levels of motivation at the fifth-grade level prompted the research team to further explore how these students perceived mathematics.

Identifying participants. Once the research team established that a study of fifth-grade students was warranted based on the EMMI results, they examined the survey data further to identify a participant pool for Phase Two. The overall research questions prompted researchers to limit the participant pool to those who displayed the highest levels of motivation across the four classes rather than taking a random sample from all who were willing to participate. Out of 62 fifth-grade students, 53% or 85.5% responded with motivation levels in the moderate to high range. These students were spread across the four classes with 8 students in Classroom A, 15 in Classroom B, 17 in Classroom C, and 13 in Classroom D. Based on these results, the research team recruited five students from each of the fifth-grade classes who displayed the highest levels of motivation on the EMMI.

Phase Two

Six overarching themes emerged in Phase Two that offer possible explanations for these students' high reported motivation for mathematics: (a) role of the teacher; (b) present value of math; (c) future value of math; (d) role of achievement; (e) classroom environment; and (f) connections. These themes are discussed below and interview excerpts are included in Table 2 to provide illustrative examples. The research team also determined how often themes were identified across all Phase Two participants. These findings are displayed in Table 3. To clarify, one-fifth grade teacher, identified as Ms. Phillips, is the mathematics instructor for all fifth-grade students. During this study, Ms. Phillips was finishing her dissertation for a doctorate in education. She had been teaching for over 20 years, and although she did not have a specialization or a degree in mathematics or mathematics education, she reported that she enjoyed doing and teaching mathematics.

Themes emerging from student interviews.

Role of the teacher. Students described their teacher along three main subthemes: (a) Instructional practices; (b) Teacher's perceived value of mathematics; and (c) Interpersonal support. Students often mentioned the teacher's use of group pairings, questioning, and discussion as positive characteristics of her instructional practice. However, while students expressed value in tasks that were hands-on and required a variety of strategies to solve, they often viewed their role as passive while the teacher was active during lessons. Students often described instances where the teacher would verbally communicate the importance of mathematics for both present and future goals. They also expressed how much she enjoyed doing mathematics and how excited she acted during lessons. Students described their teacher as caring, kind, funny, patient, and always willing to help during lessons. Students focused primarily on their teacher's helpfulness during instruction and expressed a high level of comfort in interacting with their teacher, especially when seeking help for difficult math topics.

Present value of mathematics. Many students indicated a high level of present value for mathematics by

Table 2
Examples of Themes from Interview Transcripts

Major Themes	
Role of the teacher	▪ "She tries to put like someone who's really good at math in a group with some of the ones that really need help in math. Two people, two really smart people in math in a group with some of the people who need help in math. That's what she does." (Interview 3) • "It (Math) makes me feel good because I know that I have a teacher that listens and helps us with the questions we have." (Interview 4) ▪ "She makes math fun, we get to play games. Last time we got to do the little chemicals with the soda" "Oh I know what she's talking about. She's talking about with the pints and gallons and how we had to put them in order and all that stuff." (Interview 6)
Present value of mathematics	▪ "You get to answer more difficult problems, but then again you get to find new ways to answer the different problems. Like for instance, if you go, if you learn something new then you go off to another place, new school or new college, whatever you're going to go, you can just go back and just remember the thought and the different formulas to get that answer." (Interview 10) • "Like art, because you have to measure a distance, I mean like how big something is. You have to use a ruler just to figure out how big something is." (Interview 4) • "Well, we go grocery shopping and clothes shopping. We need math because we have to add up all the prices to be sure that you do have enough for it. Me and my cousin play a game where we have to figure out how much it will be. Because it can be 50% off a shirt and everything." (Interview 3)
Future value of mathematics	• "Well, um, maybe when I'm a paleontologist, I would like, predict how long the bug will be and how many bones there are." (Interview 10) • "I'm going to be a chef when I grow up and you know you got to tell about the pints and quarts and cups." (Interview 6) • "I want to be a fashion designer, so I have to tell how much I will have to make in stores and if they are big or little." (Interview 9)
Role of achievement	• "She lets us redo our test. She lets us think about it instead of other teachers just rushing us. And she just, she helps us during tests sometimes." (Interview 1) • "On the test, we might go to her and ask her, 'we don't really get this answer, can you help me out?' She basically just helps us do it or she, or she explains how to do it and we just go back to our seats and do it." (Interview 4) ▪ "When we do tests, when people not done (sic), she be like, 'I'm going to give you an extra 20 minutes.'" (Interview 6) • "Like say you're on a test . . . when you are finished, she'll grade your paper. She'll look over your test. She'll send you back to your seat (with the test) but she'll say just keep trying and don't give up." (Interview 8)
Classroom environment	• "Like she doesn't just stay there and just tell us all the answers. She's like let's work together and come up with an answer to a problem" (Interview 8). ▪ "And in her class, it's never like there is a wrong, there is a right or wrong answer in her class" (Interview 2). • "Some problems can be like really, really hard that I can't figure out by myself. Like I can go ask a student that got it right and ask for help." (Interview 4) • "She gives me choices." (Interview 6)
Connections	• "Well, it's like she teaches us about real life and stuff, real life things." (Interview 1) • "It's just fun and then she like makes it easy by putting examples of how we use it." (Interview 6) ▪ "She applies it to real life things . . . like with geometry, like with structures, how they need to be built. Like construction. How they need to be built just to stand." (Interview 8)

describing it as an enjoyable or fun subject. These students valued a challenge in mathematics lessons and thrived on attempting tasks independently before receiving direct help from the teacher. This independence was supported by students' problem-solving strategies. When asked what they would do if confronted with a difficult mathematics problem, students described strategies such as working with their peers or breaking the problem into manageable parts to find ways to solve it correctly. In addition, students described the need to keep trying to find ways to solve a problem that was difficult, indicating a high level of persistence for completing tasks.

Future value of mathematics. In terms of utility value, students tended to view mathematics as a future-oriented discipline. For example, students described its importance in college and careers. Students tended to view

Table 3
Quantitized Data from Phenomenological Analysis

Themes and Subthemes	Number of Participants	Percentage of Participants
Role of the teacher		
Instructional practices	18	90%
Teacher's perceived value of mathematics	11	55%
Interpersonal support	20	100%
Present value of mathematics		
Challenging and fun	17	85%
Problem solvers	14	70%
Persistence	11	55%
Future value of mathematics		
Career oriented	16	80%
Role of achievement		
Priority on grades and testing	13	65%
Teacher's lack of emphasis on testing	10	50%
Classroom environment		
Discourse	16	80%
View of mistakes	5	25%
View of competition	10	50%
Connections		
Teacher's priority placed on connections	17	85%

mathematics as applicable primarily later in their lives when they would be required to use their math skills in the context of their future career. When prompted, students articulated present utility of mathematics, such as purchasing items while shopping or using measurements in cooking were described. However, students' initial responses about the usefulness of mathematics revolved around future uses in potential careers such as interior design, astronomy, and medicine.

Role of achievement. Students tended to equate success in mathematics with receiving good grades. Since most students who participated in the interviews had experienced academic success in mathematics, this success had served to reinforce their value of mathematics as an important subject. However, there were students included in the interviews with lower levels of academic success (described as having a C or lower) and still displayed high levels of mathematics motivation, indicating that achievement is not necessarily a predictor of motivation.

Students also mentioned both the standardized tests given periodically throughout the year and the culminating state test as an indicator of mathematics success. However, students described instances when Ms. Phillips would alleviate stress related to testing by helping them with answers, letting them take the test home, or working through problems as a group. The students viewed Ms. Phillips as placing a low priority on testing in the mathematics classroom, which they stated was very different from teachers in the past.

Classroom environment. Students emphasized their ability to work with each other and engage in discussions during lessons as a positive attribute toward the classroom environment. They also described their level of comfort in engaging in discourse with Ms. Phillips whether it was regarding questions about a task or alternative methods of doing a task. When prompted about how they reacted to making mistakes during mathematics lessons, students described the need to figure out their mistakes or to help each other during lessons. Healthy competition was valued by some students, for instance, trying to finish a task before another group or find a different way to solve the problem. However, often students said they did not feel the need to compete with their classmates because they could learn from each other, indicating a high level of self-confidence and a sense of trust among their peers.

Connections. When asked to describe a typical mathematics lesson or to describe the characteristics of their mathematics lessons that they most enjoyed, students would identify instances when Ms. Phillips would ask them to make real-world connections to the mathematical content they were learning. Students described instances where making these connections make mathematics "fun" or "easy." They described instances where Ms. Phillips intentionally sought out connections within a lesson and instances where they were able to talk to their peers and made connections on their own.

Themes emerging from classroom observations. While the student interviews provided a wealth of information about perceptions of mathematics and mathematics motivation, it was unclear if the student responses related to classroom instruction (in particular, those categorized under the Role of the Teacher, Role of Achievement, Classroom Environment, and Connections) were representative of actual practice. For this reason, the research team further explored how Ms. Phillips might be influencing mathematics motivation through her instructional practice. The research team focused observations on teacher practice as a means to confirm student perceptions of practice in interviews. Three major themes, described below, emerged from these observations that served to confirm student descriptions of how they experienced mathematics in interviews: (a) Respect for peers, (b) Increased discourse, and (c) Instruction and management decisions.

Respect for peers. It was evident that Ms. Phillips had prioritized setting mathematical norms with her students

such as fostering a sense of respect between herself and her students and among the students themselves. Often Ms. Phillips reminded students of the need to respect each other's perspectives and ideas during group discussions and that if alternative arguments are presented, they must be presented with justifications. It was also clear that students in these classes were not afraid of making mistakes and saw mistakes as an opportunity to help each other rather than judge each other negatively.

Increased discourse. Students across all observations showed the ability and the willingness to engage in discussions with each other and with their teacher during mathematical tasks. The majority of instructional time was spent in whole group or small group discussions where the teacher asked open-ended questions eliciting student responses. The students, however, also felt comfortable presenting alternative arguments to the teacher and challenging her ideas as well as those from their peers. While teacher-to-student and student-to-student interactions can be commonplace in the mathematics classroom, these fifth-grade students were especially comfortable engaging in student-to-teacher interactions.

Instruction and management decisions. There was a dichotomy between Ms. Phillips' instruction during the introductory phase of the lesson in the first 20 minutes after students enter the classroom and during the main phase or what she calls her "actual" lesson (the remaining 40 minutes of instruction). This dichotomy was present for every classroom observation. Ms. Phillips essentially began every lesson with 20 minutes of test preparation for the upcoming state standardized test for fifth grade. Instruction during this review period was didactic in nature where Ms. Phillips presented problems and asked students to solve individually. Then as a class, they reviewed the problems with Ms. Phillips providing additional information about test-taking skills, such as omitting improbable responses or checking work repeatedly.

During the second part of the lesson, Ms. Phillips relied on an inquiry-based mathematics curriculum for the overall design of the mathematical tasks that were implemented and the questions that she asked as students engaged in the task and while reflecting on the task. A review of the curriculum revealed that Ms. Phillips stayed fairly close to the original lesson design written in the textbook. It is unclear if Ms. Phillips would rely on didactic instruction, similar to the first fifteen minutes of each lesson, if she did not have the support of the textbook to guide lesson planning and questioning during lesson implementation. It is also unclear if Ms. Phillips' instruction during the first third of each lesson was the result of increased pressure during annual testing time or if it was her natural practice. When Ms. Phillips was teaching in a student-centered manner, she often encouraged students to make connections between what they have experienced in school or at home with what they are learning in the lesson. Students seemed highly engaged and excited when they were able to discuss examples from their own experiences. In addition to these intentional connections, Ms. Phillips demonstrated the ability to make instructional decisions based on assessment gathered during lessons. Ms. Phillips taught a similar lesson to all of her students throughout the day; however, she was able to improve these lessons consistently based on her observations of students during tasks. Finally, Ms. Phillips displayed a positive disposition throughout all observations. She demonstrated a love for mathematics by showing enthusiasm about discussions and mathematical tasks and she managed behavior problems (that were typically the result of overexcited students getting ready to engage in a task) with positive behavior techniques.

Connections between interviews and observations. The classroom observations primarily related to four themes emerging from student interviews: (a) role of the teacher; (b) role of achievement; (c) classroom environment; and (d) connections. Consistencies were observed between the paired interviews with fifth-grade students and the classroom observations. Under the "role of the teacher" theme, students described the desire for their teacher to encourage discourse through group work and to implement hands-on, challenging tasks, all of which were observed during lessons. However, students often described their role as being passive in the interviews (where the teacher would tell them step by step what to do in their groups). In observations, when Ms. Phillips was implementing a lesson rather than a task related to test preparation, students were primarily active, determining their own strategies for solving problems. In regard to the "classroom environment" theme, students expressed feeling comfortable and confident during mathematics lessons and that there was a positive group dynamic among their peers (for example, engaging in healthy competition or working with each other to learn from mistakes). Lesson observations indicated that Ms. Phillips placed a priority on establishing a level of respect in the classroom and an environment that encouraged collaboration. In the "connections" theme, students expressed the need for mathematics lessons to build on their current experiences and interests. Ms. Phillips often provided opportunities for students to make connections between content and context. For example, when discussing

capacity, she brought in real-life objects for students to use in exploration and later asked them to bring in objects from home. The primary difference that occurred between the lesson observations and the paired interviews was Ms. Phillips' view of assessment and the role it plays in determining student success. Students often described Ms. Phillips as placing a low priority on testing, as stated in the "role of achievement" theme, but almost a third of every observation was spent preparing students for the state standardized test. This disconnection could indicate that Ms. Phillips altered her instructional practice because of the time of year the observations occurred (in the month leading up to the implementation of the state standardized test). Regardless of this difference, findings determined through classroom observations seemed to correspond with four of the overarching themes developed as a result of the paired interviews that related to classroom practice.

Discussion and Implications for Practice

The qualitative analysis of student interviews revealed several key themes, which were influential in these students' high reported levels of motivation in mathematics. While these findings are specific to a particular grade level of students in one setting, they could inform the identification of factors that sustain student motivation in mathematics during the progression from early to late elementary grades. In turn, these findings could also provide insight into factors that could contribute to supporting student motivation for mathematics across the transition to middle grades.

Central themes across participants included opportunities for self-direction and peer collaboration during instruction, the critical link between current mathematical topics and future applications, and the importance of positive perceived teacher interpersonal interactions. In addition, students placed a particular priority on the need to deemphasize the importance of standardized testing. While students valued high grades in mathematics as a measure of success (and therefore, higher levels of motivation), they were motivated by the fact that Ms. Phillips did not emphasize test grades, but rather performance during tasks as a measure of success. This emphasis on personal performance may have fostered a mastery goal orientation in these fifth-grade mathematics students. Research has shown that a mastery orientation to learning can support students' motivation, particularly their efficacy and value for a content area (Midgley, Kaplan, & Middleton, 2001). Students focused on test performance, specifically in relation to competition with other students, tend to report lower levels of academic motivation and display lower levels of efficacy for their academic competency (Midgley et al., 2001).

These findings point toward the important part that teachers play in engaging students in active roles during mathematics instruction, which is consistent with other studies of mathematics motivation (Byrnes & Wasik, 2009). However, while many studies point to teacher beliefs and instructional practices as influential toward motivation, this study attempts to disentangle how teachers can best support student motivation through instructional practices. Teachers play a central role in helping develop effective problem-solving strategies, which in turn provide students with the tools they need to operate more independently during instruction. Instruction in effective problem-solving strategies may also serve to elevate students' self-efficacy in mathematics as they develop skills for success as independent learners. In addition, teachers can provide students with a feeling of independence and self-direction by providing open-ended assignments and choice among several viable options for extending instruction on topics in mathematics. They can also build environments that encourage substantive discourse and that focus on engaging student interest by making connections during lessons.

Student interviews and classroom observations suggest that Ms. Phillips contributed to the overall high levels of mathematics motivation for fifth-grade students in this setting. However, while teacher practice influenced student motivation, it was not the only factor present. Student interviews also indicated that students' present and future value of mathematics, along with their self-efficacy for mathematics content, also contributed to their levels of motivation. In terms of present value of mathematics, these students identified being presented with a challenge, finding different ways to solve problems, and high levels of persistence as key characteristics to enjoying math. In particular, when students discussed whether or not they felt like they were good at math, persistence and feeling like they could succeed at solving problems were key indicators of self-efficacy toward mathematics content. In addition, students saw mathematics as something that was important to learn now because it will be useful in the future. These students saw themselves entering into careers where mathematics might be helpful in succeeding. These findings indicate that students in this setting had high levels of confidence in their abilities to succeed. Due to the nature of the research questions focusing on highly motivated students, it is unclear if students with lower motivation would have the same levels of confidence, however, past research would indicate otherwise (Pintrich, 2003).

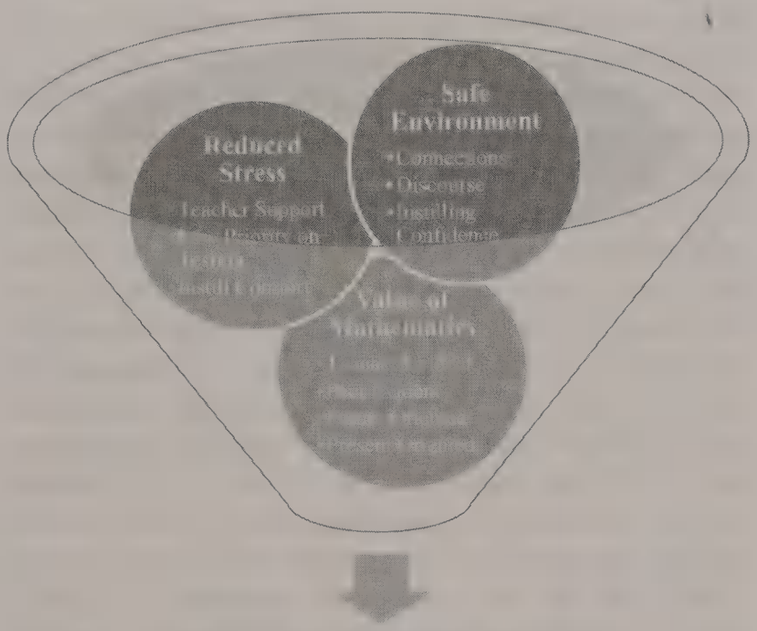

Figure 1. Potential model for building elementary mathematics motivation.

The themes emerging from the paired interviews and triangulated with the classroom observations form the basis for the potential motivation model displayed in Figure 1. This model incorporates three main components that could potentially build motivation in elementary age students: (a) Establishing a safe mathematical environment; (b) Encouraging students' value for mathematics; and (c) Reducing external stress related to mathematics. This model is meant to inform teachers about ways they could potentially increase levels of students' mathematics motivation in their own settings. The three components of the motivation model are intertwined because they all revolve around teacher practice. In fact, components one and three ("Establishing a safe mathematical environment" and "Reducing external stress related to mathematics") were directly identified in classroom observations during the course of this study. In terms of establishing a safe mathematical environment, students identified Ms. Phillips' ability to make connections about mathematical content and real-world ideas that were of interest to them. In addition, students discussed how Ms. Phillips always allowed them to work through tasks together and that the classroom was an open space for discussion. Finally, students identified Ms. Phillips' ability to provide consistent encouragement and promote confidence in students during mathematics lessons. In terms of reducing external stress related to mathematics, students described how Ms. Phillips would allow them to redo problems on tests or take tests home to encourage success. They also identified Ms. Phillips' ability to increase their comfortable level during lessons by making mistakes an opportunity for learning. While "Encouraging student's value for mathematics" was not specifically observed in practice, it was clear from student interviews that teachers should both display and encourage their students to develop present and future value for mathematics. Students described Ms. Phillips as someone who loved math and who promoted the utility of mathematics in their own lives.

Limitations and Recommendations for Future Research

These results provide insight in regard to domain-specific motivation in mathematics. However, this study examined highly motivated mathematics students in one setting at one point in time. Further, these students all had the same mathematics teacher when this study occurred. There were no students with low motivation levels sampled for analysis in this study. It is unclear why there were students in this grade with lower levels of motivation (14% across the fifth grade) because the research questions did not call for inclusion of students with low levels of motivation. However, possibilities for low mathematics motivation based on previous research could include factors external to the classroom or previous classroom experiences. Future studies should compare low and high levels of motivation to determine if the proposed motivation model would apply for all students. The use of the EMMI provided the research team with information about the fifth grade students in this setting that they may not have found by conducting a phenomenological exploration in isolation. Future studies could utilize the EMMI as a method of exploring strategies for participant selection, as was done in this study. In addition, this study only focused on motivational factors and did not seek to make any connections between levels of mathematics motivation and student achievement. Future research is necessary to determine the correlation between these two factors and, in particular, how student achievement and levels of motivation change based on teacher practice. Finally, the motivation model described above is developed based on the perceptions of students in this particular setting. Future research is necessary to explore the generalizability of this potential model.

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Keywords: Mathematics; Motivation; Elementary.

Elements of Design-Based Science Activities That Affect Students' Motivation

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The primary purpose of this study was to examine the ways in which a 12-week afterschool science and engineering program affected middle school students' motivation to engage in science and engineering activities. We used current motivation research and theory as a conceptual framework to assess 14 students' motivation through questionnaires, structured interviews, and observations. Students reported that during the activities they perceived that they were empowered to make choices in how to complete things, the activities were useful to them, they could succeed in the activities, they enjoyed and were interested in the hands-on activities and some presentations, they felt cared for by the facilitators and received help when they were stuck or confused, and they put forth effort. Based on our examination of data across our three data sources, we identified motivating opportunities that were provided to students during the activities. These motivating opportunities can serve as examples to help both formal and informal science educators better connect motivation theory to practice so that they can create motivating opportunities for students. Furthermore, this study provides a methodological example of how students' motivation can be examined during the context of authentic science and engineering instruction.

More scientists and engineers are needed in the United States to fill the current demand (President's Council of Advisors on Science and Technology, 2010). Because researchers have identified middle school as a critical time to interest students in science, technology, engineering, and mathematics (STEM) topics and careers (e.g., Tai, Liu, Maltese, & Fan, 2006), we implemented an afterschool curriculum titled *Studio STEM* to interest and motivate students to engage in STEM-related fields and to teach basic science concepts. We hypothesized that the synergy of the curriculum, activities, technology, and mentoring in an informal setting could motivate students from rural, economically depressed communities.

The primary purpose of this study was to examine the ways in which a 12-week implementation of Studio STEM affected middle school students' motivation and engagement in science and engineering activities. We used current motivation research and theory as a framework to assess students' motivation. We surveyed, interviewed, and observed students participating in Studio STEM to assess factors that influenced different aspects of their motivation. Our analysis revealed examples of how informal science instruction can motivate middle school students, and we believe that understanding these motivating opportunities can help educators and researchers better connect motivation theory and science instruction.

Background

Studio STEM

Studio STEM was a 3-year afterschool and summer program that used a design-based approach and an interdisciplinary curriculum to help middle school students learn about energy conservation. The principal goal of Studio STEM was to engage students in interesting projects related to environmental issues that allowed them to acquire critical knowledge, skills, and dispositions. Using a social constructivist approach (Vygotsky, 1978), teachers (referred to as *site leaders*) and engineering and science undergraduates (referred to as *facilitators*) worked with upper-elementary and middle school students on a curriculum with authentic problems in energy sustainability. Studio STEM was based upon the following

design principles: (a) an interdisciplinary curriculum to interest and engage students in fundamental concepts in alternative energy resources, energy transfer, and energy sustainability through problems related to environmental issues that affect animals; (b) an active, inquiry-based learning experience through engineering design activities to engage students in real-world projects that promote conceptual change and problem-solving strategies; (c) an informal learning arrangement organized to approximate a design studio to allow creative exploration and exchange of problem strategies and solutions; (d) appropriation of Internet resources and social network forums to expand the learning space; and (e) a workforce development-focused endeavor to serve rural Appalachian communities by training middle school teachers and undergraduate facilitators, as well as cooperating with industry, institutional, and community partners.

Learning Through Design-Based Science and Engineering Activities

Studio STEM employed active, inquiry-based learning through science and engineering design activities that engaged students in authentic problems to promote motivation, conceptual change, and design thinking. The learning strategies that guided this project reflect the vision detailed in the National Academy of Engineering and National Research Council's (NRC) publication, *Engineering in K-12 Education* (Katehi, Pearson, & Feder, 2009), and the Next Generation Science Standards (NRC, 2013). These calls for reform emphasize student-centered environments where active inquiry is a primary vehicle for learning (American Association for the Advancement of Science, 1993; NRC, 2013).

Design-based learning is a form of problem-based learning. When students engage in design-based learning, relevant problems provide the context and motivation for all the activities that follow (Barrows & Tamblyn, 1980). Students learn skills and facts as they progress through the process of solving the problem with a design approach. In a sense, Studio STEM provided a "practice field" (Barab & Duffy, 2000) where participants engaged in activities that simulated ones that can be found in the real world. These practice fields emphasized (a) ownership of the inquiry process, (b) an opportunity for reflection, (c) coaching and modeling of thinking skills, (d) collaborative and social activities, (e) learning that is motivating, and (f) problems that are not oversimplified (Barab & Duffy, 2000). Moreover, the use of authentic problems allowed participants to apply design thinking to their lived experience and, thus, better understand the usefulness of what they were learning. Researchers (e.g., Fusco & Barton, 2001) have noted that students' perceptions of the usefulness of the problem-solving process were centrally connected to the ways that they began to see a future in STEM careers. For example, Basu and Barton (2007) argued that students from economically depressed communities develop a sustained interest in science when learning experiences are connected with their own futures and when they can envision their role in designing solutions to authentic problems.

Theoretical Framework

The MUSIC Model of Motivation

The MUSIC[SM] Model of Motivation (Jones, 2009, 2010b) was designed to help instructors apply current motivation theories by designing instruction that engages students in learning. The MUSIC model consists of five components that have been derived from research and theory as ones that are critical to student engagement in academic settings: eMpowerment, Usefulness, Success, Interest, and Caring (MUSIC is an acronym). Validity evidence indicates that these five components are correlated, yet distinct (Jones & Skaggs, in press; Jones & Wilkins, 2013a, 2013b). Five key principles of the MUSIC model are that students are more motivated when they perceive that (a) they are *empowered*, (b) the content is *useful*, (c) they can be *successful*, (d) they are *interested*, and (e) they feel *cared* for by others in the learning environment. The MUSIC model does not introduce new motivation constructs; rather, it presents instructors with guidance in designing instruction (e.g., Jones, 2009, 2010b) by summarizing decades of research in motivation and translating it to language that is more understandable to instructors than the jargon used by motivation researchers (e.g., self-efficacy, attainment value). When instructional environments are designed using the MUSIC model, research and theory predict that students will be more engaged. The MUSIC model can also serve as a tool for researchers to use in understanding the impact of instruction on students' motivation (e.g., Jones, 2010a; Jones, Epler, Mokri, Bryant, & Paretti, 2013; Jones, Osborne, Paretti, & Matusovich, 2014).

The *empowerment* component of the MUSIC model refers to the amount of perceived control that students have over their interactions with their learning environment (Jones, 2009). Research related to empowerment has been conducted by researchers studying autonomy within the framework of self-determination theory (Deci & Ryan, 2000). Instructors can empower students by supporting their autonomy, such as by providing them with choices and the ability to make decisions. The

usefulness component of the MUSIC model involves the extent to which students believe that the coursework (e.g., assignments, activities, readings) is useful for their short- or long-term goals. Students' goals are important because their motivation is affected by their perceptions of the usefulness of what they are learning for their future and in the real world (Wigfield & Eccles, 2000). One implication is that instructors need to ensure that students understand the connection between the classwork/activities and their goals. The *success* component of the MUSIC model is based on the idea that students need to perceive that they can succeed at a task if they put forth the appropriate effort. Self-perceptions of competence (i.e., one's beliefs about one's ability to succeed) are central to many motivation theories, such as self-concept theory (Marsh, 1990), self-efficacy theory (Bandura, 1986), self-worth theory (Covington, 1992), goal orientation theory (Ames, 1992), and expectancy-value theory (Wigfield & Eccles, 2000). Instructors can foster students' success beliefs in a variety of ways, including making the course expectations clear, challenging students at an appropriate level, and providing students with feedback regularly. The *interest* MUSIC component includes situational interest, which refers to the immediate, short-term enjoyment of instructional activities. Interest is related to many positive outcomes, including attention, memory, comprehension, deeper cognitive engagement, goal setting, learning strategies, and achievement (Hidi & Renninger, 2006; Schunk, Meece, & Pintrich, 2014). Instructors can trigger students' situational interest by designing instruction and class work that incorporates elements such as novelty, social interaction, games, humor, or surprising information, or that engenders emotions (Bergin, 1999). The *caring* MUSIC component is derived from research in the areas of belongingness, relatedness, connectedness, affiliation, involvement, attachment, commitment, bonding, and sense of community (e.g., Baumeister & Leary, 1995; Deci & Ryan, 2000). Caring can be divided into two components: academic caring and personal caring (Jones & Wilkins, 2013a, 2013b). When students have close relationships with their teachers and peers, they tend to be more engaged in the classroom and perform better academically (Bergin & Bergin, 2009). Academic caring specifies that instructors need to demonstrate to students that they care about whether or not their students successfully meet the course objectives. Personal caring includes the idea that students need to perceive that their instructor and/or other students care about their welfare.

Research Question

Our research question for this investigation was: In what ways does Studio STEM affect middle school students' motivation and engagement in science and engineering activities? To answer this question, we studied a 12-week implementation of Studio STEM by analyzing data collected through questionnaires, structured interviews, and observations.

Method

Participants

We obtained a convenience sample from students enrolled in a K–7 school in rural, southwest Virginia that included all 14 (4 girls and 10 boys) of the sixth- and seventh-grade students who participated in Studio STEM at this school. Students met once a week after school seven times in the fall and five times in the spring (each session lasted 90 minutes).

Save the Seabirds Curriculum

In our study, we examined the 12-session Save the Seabirds curriculum module (available at http://www.auburn.edu/~cgs0013/engineering.htm) in which students designed, built, tested, and re-tested a mini solar-powered car to pull as much weight as possible. They also tested different solar panels, motors, and methods for transferring motion from motor to wheels. Activities targeted alternative conceptions of force and motion, and students learned about petroleum use and the Law of Conservation of Energy in the context of a scenario in which solar power could be used to reduce dependence on petroleum, which can spill and harm seabirds. The instructors included the Studio STEM project leader, a science teacher from the school where Studio STEM was implemented, and two undergraduate engineering students from a nearby university.

The format of the sessions varied. In some sessions, the teacher presented slides on a projector to orient students to the topics and to provide content information; afterwards, students engaged in activities. In other sessions, especially in the last five sessions, the teacher conducted fewer presentations and students spent more time engaged in the activities.

Data Sources and Collection

We collected and analyzed both qualitative and quantitative data, and then triangulated those data to form a deeper understanding of students' motivation and engagement in Studio STEM. Although our sample size was limited, we posit that it was sufficient considering our focus on qualitative methods (Glaser & Strauss, 1967).

Questionnaire. All 11 students who attended the last Save the Seabirds session completed a questionnaire that included items about their perceptions of the 12 sessions.

Students reported their perceptions of each of the MUSIC model components using the MUSIC Model of Academic Motivation Inventory—Middle School version (Jones, 2012), which includes four empowerment items, three usefulness items, four success items, three interest items, and four caring items. This inventory has been shown to adequately represent the five-factor structure of the MUSIC model (i.e., empowerment, usefulness, success, interest, and caring) with students in the fifth, sixth, and seventh grades (Jones & Wilkins, 2013b, reported empowerment $\alpha = .70, .72$; usefulness $\alpha = .82, .80$; success $\alpha = .79, .84$; interest $\alpha = .78, .77$; and caring $\alpha = .78, .85$; see the Appendix for sample items). The questionnaire also included a 4-item scale that measured the amount of perceived effort that students put forth in Studio STEM. This measure is based on the 5-item Effort/Importance scale that is part of the Intrinsic Motivation Inventory (Plant & Ryan, 1985) and has been shown to have adequate psychometric properties (Jones, 2010a). All of the items on the questionnaire referred to the "Studio STEM activities" related to the Save the Seabirds curriculum and were rated on a 6-point Likert-type scale (1 = *strongly disagree*, 2 = *disagree*, 3 = *mostly disagree*, 4 = *mostly agree*, 5 = *agree*, 6 = *strongly agree*).

Interviews. Three rounds of structured interviews were conducted with students. The first round of interviews occurred during the first session ($n = 14$; 100% of the students enrolled in the program), the second round of interviews occurred during the seventh session ($n = 11$; 79% of the students), and the third round of interviews occurred after the twelfth session when the program was complete ($n = 9$; 64% of the students). We interviewed all of the students who attended the sessions in which we conducted the interviews; some students were absent during the second and third interviews. Each interview lasted from 10 to 20 minutes. The interview protocol was structured, with two to five questions pertaining to each of the five MUSIC components. The goal of the interviews was to uncover students' perceptions of the presence or absence of the five MUSIC components in the curriculum activities.

The purpose of the first interview was to assess why students decided to participate in the program, what they knew about the program, their beliefs about the value of science, and their science ability beliefs. The second and third interviews began by showing students a summary list of what they had done during the sessions since the last time they were interviewed. They were asked to think about the sessions in which they participated during that time period only, and to respond to the questions in reference to those sessions only. Prior to each open-ended question, the interviewer showed students blocks consisting of one, two, or three connected, plastic cubes labeled "*Not very*" (or "*Very little*"), "*Somewhat*" (or "*Some*"), or "*Very*" (or "*A lot*"), respectively. An example question for the interest component was:

> The small block means that the presentations were not very interesting to you, the medium block means that the presentations were somewhat interesting to you, and the large block means that the presentations were very interesting to you. Which block do you think shows how interesting the presentations were to you? [Response] Okay, you picked the [small, medium, large] block. What was interesting about the presentations?

This procedure of showing the blocks, explaining what each meant, asking students to choose one, and then asking students to explain their response was used for each MUSIC component.

Observation data. We collected observation data during all sessions. All observers were trained on data collection procedures, including the use of two forms (described next). The observers were selected because they had received extensive training pertaining to the MUSIC model and had studied academic motivation at the doctoral level. The observers did not interact directly with the students or instructors.

MUSIC Model Observation Form. One researcher completed a MUSIC Model Observation Form during each session to assess the prevalence of the five MUSIC model motivation components during the session. The form allowed the observer to document (a) the time that the evidence was observed, (b) indicators of the MUSIC components, (c) a description of the activity in which the indicator occurred, (d) relevant quotations, and (e) the names of the students involved. The indicators allowed the observer to document when he/she observed evidence that students perceived that (a) they were empowered, (b) the content was useful, (c) they could be successful, (d) they were interested, and/or (e) they felt cared for by others in the learning environment. Because these MUSIC components have been shown to lead to motivation and engagement (Jones, 2009), the documentation of these MUSIC indicators provided some evidence of student motivation and engagement. Each observer was trained to look for student–student and instructor–student interactions, instructional practices, and student behaviors that could suggest that elements of the instructional environment facilitated their motivation. For example, observers

attended to students' verbalizations and/or behaviors that suggested that they felt success (e.g., a student pumping fists and saying "Yes!" after succeeding at a task). As another example, an observer could indicate that empowerment was supported if he/she noted that the instructors provided students with a meaningful choice in how to design their solar-powered cars.

General Observation Form. One researcher completed the General Observation Form during every session to collect information related to the session's presentations and activities, as well as students' motivation and engagement. Observers were trained to use the form, which was arranged into three sections: (a) *Context*, which allowed for the collection of data relevant to the physical layout of science activity spaces and the circumstances that impacted these activities; (b) *Description of Activities*, which allowed for a description of the students' activities; and (c) *Behavioral Engagement*, which allowed for the collection of curricular and/or instructional elements that led students to be engaged behaviorally.

Data Analysis

Descriptive statistics were computed for the questionnaire scales. The interviews were audio-recorded and transcribed verbatim. Two of the authors developed a list of codes using thematic whole text analysis, which was informed by the analytic procedure developed by Glaser and Strauss (1967). Next, two authors coded all interviews according to the identified codes and compared results. When there was a difference in the coding, the items were discussed and a final code assigned. We calculated the inter-rater reliability as 86.3% for the first interview, 82.5% for the second interview, and 85.7% for the third interview.

Trustworthiness and credibility were enhanced, and results deepened, through triangulation with the results of the observation forms. We coded all motivation-related observations noted in both forms. For our analysis, we used the existing codes developed from the student interviews, which we coded prior to coding the observations. We matched the relevant excerpts within the observation forms to the interview codes and created new codes when we did not have an interview code that matched the observation excerpts. When excerpts on the observation forms from the same session were labeled with the same code, we "counted" the code only once (i.e., the same code was not counted more than once on any one session).

Results

Questionnaire

On the 6-point Likert-type scale, students ($N = 11$) generally reported that, during the Studio STEM (Save the Seabirds) activities, they perceived that: they were empowered ($M = 5.23$, $SD = 0.74$), the activities were useful to them ($M = 4.67$, $SD = 0.97$), they could succeed in the activities ($M = 5.55$, $SD = 0.62$), they enjoyed and were interested in the activities ($M = 5.42$, $SD = 0.60$), they were cared for by the facilitators ($M = 5.66$, $SD = 0.57$), and they put forth effort ($M = 5.48$, $SD = 0.68$). On average, students reported scores greater than 5 (*agree*) for their effort and for all of the MUSIC component subscales, except for usefulness.

Interviews and Observations

During the first interview, all of the students reported that they had participated in Studio STEM the prior year. When asked with an open-ended question why they enrolled again in the current year, many of the students (71%) said that it was because they had enjoyed participating in the program the prior year. We also asked them: "Is there something about [Studio STEM] that interests you?" Students reported that they were interested in solar cars and designing and building things, and that they liked seabirds and teamwork.

Results of the second interview (after 7 weeks of the program) and third interview (after 12 weeks) are summarized in Tables 1 and 2. Students' responses vary somewhat for the two interviews because the presentations and activities differed throughout the 12 weeks. The results of the observations are also provided in Table 2. In all, we created 118 codes, with 102 codes for the interviews and 16 additional codes for the observations that were not present in the interview codes. Of the 118 codes, 54 codes (45.8%) were used for both the interviews and observations. Of the 102 codes related to only the interviews, we observed 54 (52.9%) and did not observe 48 of those codes (40.7%) because they were yes/no responses or questions pertaining to the future (thus, they were impossible to observe). Of the 33 codes that could be observed, 26 (78.8%) were mentioned by only one student during one of the interviews (or 54.2% out of the 48 codes), five were reported by two students, one was reported by three students, and one was reported by four students. These findings suggest that the majority of the codes that were not observed were cited by very few students or could not be observed, which indicates that those codes were not prevalent in the program. Most of the interview responses (86.1%) and observations (93.5%) were consistent with the MUSIC model in that they documented instructional practices that can facilitate students' motivation (e.g., students perceived that they could be successful).

Table 1
Responses by students when shown blocks labeled with descriptors

MUSIC component		Interview 2 Not Very (Very Little)	Somewhat (Some)	Very (A Lot)	Interview 3 Not Very (Very Little)	Somewhat	Very (A Lot)
eMpowerment		1	3	7	0	1	8
Usefulness	Now	2	4	5	4	5	0
	Future	0	5	6	0	5	4
Success		0	2	9	0	4	5
Interest	Presentations	0	5	6	—	—	—
	Activities	0	0	11	0	3	6
Caring	Facilitators	0	0	11	0	0	9
	Teammates	1	6	4	—	—	—
Effort		0	1	10	0	0	9

Note. A dash (—) indicates that students were not asked about that component.

Because research and theory indicate that students put forth effort and engage in activities when they perceive that the activities have high levels of one or more of the MUSIC model components (Jones, 2009), we examined each of the MUSIC model components to gain a deeper understanding of which elements of the Studio STEM activities contributed to students' motivation. We discuss the findings in the following sections in the order of the MUSIC acronym for organizational purposes only; we do not mean to imply that any one of the components was more important than the others in motivating students.

Empowerment. Related to empowerment, we asked students about the choices they had in the Studio STEM sessions. Students discussed the broader choices that they had, such as choices related to how to build assigned projects and the use of materials (e.g., one student responded, "Well, I mean they gave you the requirements of the activity, but then basically you got to choose how you wanted to do it, as long as it met the requirements"). They also discussed specific choices, such as how many cubes to put in a cup when building a lift (e.g., another student explained, "Well, you got to make choices on how many cubes you could put into the basket, you got a choice on how to connect your circuit's wires to make your solar panel work"), the choice of their group partners, and what to write on their storyboards (i.e., posters filled-in each day that tracked their learning). These student responses were corroborated with the observation data, as shown in Table 2. The observers also documented that students were empowered in several additional ways, such as in selecting their seating arrangements and controlling the pace and direction of the lessons and activities. One often-cited strength of design-based science is that it is "student-centered" because it allows students to direct their own learning (Kember, 1997). Our data are consistent with this claim and provide specific examples as to when students had choices.

Usefulness. Students reported that they found the program to be *somewhat* useful to their lives at that time and in the future. When asked about the aspects of the program that were useful to their lives currently, different students reported different topics that were useful to them, resulting in a list of activities, such as learning about motors, electricity, energy, gears, tires, and combustion engines. Three students also noted that what they learned in the program had been useful in their science classes, indicating that they found the curriculum concepts to transfer to their in-school science learning. A few students thought that the program was not very useful to their current lives. For example, one student explained that the program was not very useful to his current life because he could not build anything (e.g., a solar car) outside of school: "Because I couldn't build really anything right now, and solar cells are really expensive and I wouldn't really know how, what they'd be used for . . . . But it's something in the future I'd need to know." Another student noted that the program did not overlap with science class topics. In contrast, a student explained that the program was not very useful because it was *only* applicable to science class. Interview results are largely consistent with the observations, and the observations added that the facilitators often provided rationales for rules and related the program to the real world, which could add to students' perceived usefulness.

When asked about how what they did was useful for the future, some students reported that it was useful for getting into college or succeeding in college, and others noted that it was useful for becoming a scientist or engineer (e.g., one

Table 2

Interview questions and number of interview responses and observations for each code

Questions and Codes for the MUSIC Model Components (Organized by MUSIC Component)	Interview After: First 7 weeks	Interview After: Last 5 weeks	Observations During†: First 7 weeks	Observations During†: Last 5 weeks
Empowerment				
What choices did you have in Studio STEM (in these sessions)?				
Choice of how to build the solar cars	0	8	0	3
Choice of how to complete things	2	5	2	2
Choice of how to build my motor to pull up the cup with cubes	5	0	2	0
Control over the use of materials	0	0	4	3
Choice of how to put the gears together	2	0	1	1
Choice over researching on electricity, energy, batteries, and solar panels	3	0	0	1
Choice to write on the storyboards	0	1	1	1
Choice of group	1	0	2	1
Usefulness (for short-term goals)				
What have you done in Studio STEM (in these sessions) that's useful to your life right now?				
Learning about motors	3	0	1	0
Learning about electricity	3	0	1	0
The rationale for the rules or expectations was provided	0	0	1	3
Learning about solar cells or cars	2	0	1	1
What I learned in these sessions has been useful in my (science) classes	0	3	0	0
Success				
What made you feel that you could be successful in Studio STEM (in these sessions)?				
The facilitators were helpful (including feedback)	3	2	5	5
There were clear instructions or expectations	0	0	3	4
I am good at science or math	3	1	0	0
There was an appropriate level of challenge (the facilitators monitored readiness)	0	0	3	3
I felt successful in working on the solar cars	0	2	0	4
I could remember and use what we learned (e.g., reviewed tasks, presentations, activities)	2	1	2	0
I felt successful in working on motors	2	1	1	0
Interest (presentations)				
What was interesting about the presentations?				
Learning about oil rigs and their effects on animals and the environment	5	0	1	0
Watching videos on force and combustion engines or how to turn electrical energy into mechanical energy (e.g., gears)	4	0	1	1
Learning about gears	0	3	0	1
Interest (activities)				
What was interesting about the activities?				
The activities were hands-on or allowed us to experiment	4	0	4	2
Building the car	0	6	0	3
Working with motors to lift up the basket with cubes	5	0	2	0
Using the Legos	0	2	2	3
Measuring the voltage and amps (multimeters)	3	0	1	0
Playing with a solar powered car inside and outside (demonstration)	2	0	1	1
Caring (instructors)				
How did they (the instructors) show that they cared about your success in Studio STEM?				
They helped when we were stuck, confused, or missed something	7	9	5	4
They asked about how we were progressing on the activities	0	1	5	5
They wanted us to be successful	2	0	3	3
They used teaching methods that would help us understand the content	1	0	4	2
They trusted me to make choices (and have good ideas)	1	0	2	3
They helped me work on the project when my partner was absent	1	0	4	1
Caring (other students)				
How did they (other students) show that they cared about your success in Studio STEM?				
My partner helped me work on the project	2	0	4	4
They wanted me to be successful	2	0	1	1

Note. Codes with fewer than a combination of four interview responses and observations are not shown. We divided the observations into those made during the first 7 weeks and the last 5 weeks to allow for easier comparison with the interview results.
†Only one observation per week was recorded even when more than one observation was noted on the observation rubrics.

student responded, "If I get a job in engineering . . . you have to understand this type of stuff to go to college, get a good job, and get good grades—stuff like that"). Students also reported more generally that it was useful for figuring out what they wanted to study in college or their future career choice. These findings are important because they indicate that this program played a role in students' thoughts about college in general, as well as about specific

career options. For example, one student explained, "I'm planning on being a robotics engineer at [University]. Whenever you guys came here, I was talking about robots and [facilitator] showed me the [university engineering program] webpage. I went home, checked it out, and it looked really, really cool." However, it is difficult to determine the extent to which students' beliefs were affected by the curriculum content versus the interactions with the facilitators, as the facilitators were undergraduate students and the program participants worked with them during each session. Perhaps talking with, and getting to know, undergraduates was also important to their perceptions of what it meant to become a college student and, specifically, an engineering student.

The results from the students' interviews and our observations were aligned fairly closely for all of the MUSIC model components except for usefulness. The usefulness of the activities was more difficult to observe without knowledge of students' interests and goals outside of the specific program activities in which they were participating. For example, one student discussed that learning about motors was useful to him because of his father's work: "My papa works on motors and fluids and stuff, so I'm going to help him do that when I get older so it'd be good to get to know all about motors and mechanical energy now." This background knowledge was unknown to the observer and, therefore, unless the student had verbalized this fact during the activity, it was impossible to document through observation only.

Success. In general, students believed that they could succeed in the program. Some of the most common interview responses were that their success beliefs derived from the helpful facilitators and site leaders (e.g., one student explained, "It was pretty hard but the facilitators, they encouraged me."). Others attributed their success to the fact that they were good at science, mathematics, or designing things (e.g., "Partially because I am very good at science . . . . Math is another strong point of mine"). Some students noted specific activities in which they felt successful, such as in working on the solar cars, motors, solar panels, gears, and measuring voltage and amps. The observers noted during seven sessions that there were clear instructions or expectations, which could have allowed students to feel successful. A few students explained that they did not feel successful during specific events, including working on the solar car (because it was challenging), using the motors to lift baskets of cubes, the quizzes, learning about voltage, and after they missed one or more sessions. However, these feelings were not common in the interview data, as only one student cited each issue. Most of the students reported that they felt they could succeed in the program, which indicates that the curriculum was designed at an appropriate level for these students.

Interest. The students reported that they were interested in the program; however, the activities were more likely to stimulate their interest than the presentations. They perceived the activities to be interesting because they were "hands-on" and allowed them to experiment with things such as building the car, working with motors, using Legos, measuring the voltage and amps, playing with a solar car, playing with gears, and making a circuit for the solar cell. For example, when asked what was interesting about the activities, one student explained: "It was very hands-on. We got to do most the things, instead of the teacher showing us what it is and stuff, we got to actually experiment by ourselves." When asked directly whether there were times when they felt that the activities were boring, none of the students reported that the activities were boring. However, the observers noted that, during one activity in which the students were reviewing and refining their solar cars, the students were less engaged, some were off-task, and the classroom environment was "slightly chaotic." In this case, the observations provided important details about the activity that were not recalled by students during the interviews.

Students' interview responses were different when they were asked about the site leader's presentations. Presentations were short (10 minutes or less) and took place at the beginning of a session to introduce new ideas or to review information. Presentations included images, text, and videos, and were designed to be engaging and interactive. Several students reported that the presentations were boring, especially watching some of the PowerPoint presentations. One student mentioned that it was boring when the site leader reviewed things that he already knew. Although some reviews may have been uninteresting, they may have helped students feel successful. That is, maybe these reviews were needed to help develop their perceptions of competence and to be successful in future tasks. As another example, two students indicated that presentations were boring when they did not get enough information or did not understand the content, suggesting that their poor ability beliefs negatively affected their experience of interest. One of the two students described what was boring: "The parts where they were talking about a whole bunch of stuff that I didn't understand. Like, like when we were talking about engines; like some stuff was mentioned that I just didn't get." These findings demonstrate the

complex interplay among MUSIC model constructs, such as interest and success.

Nonetheless, the presentations were found to be interesting sometimes, such as when they were learning about topics such as electricity, voltage, current, solar cells, motors and engines, and gears. Some students found it interesting to watch the videos on force and combustion engines, and how to turn electrical energy into mechanical energy. These interview findings were consistent with the observation findings and indicate that the activities were generally more interesting to students than the presentations, although parts of the presentations were interesting, especially the videos and when they learned something new.

Caring. For the caring component, we assessed whether students felt cared for by the site leaders, facilitators, and their teammates, separately. Students typically rated the facilitators and site leaders as highly caring. The most common way in which students reported that the facilitators and site leaders showed that they cared about students' successes was that they helped the students when needed. For example, one student said, "If we didn't know something they would help you and get you caught up . . . . They would kind of let you explore and then, even though sometimes it didn't work, they would . . . help you figure it out." Another student similarly explained, "They actually helped, they were not just standing back there, and they communicated." The observation data were consistent with this interview finding and added other details, such as that the facilitators and site leaders asked about how students were progressing on the tasks. Some students also reported that the facilitators and site leaders used teaching methods that would help them understand the content and helped them work on the project when their partners were absent.

Table 1 shows that the students felt cared for by their teammates, although less so than by the facilitators and site leaders. Several students reported that their partners helped them work on the project, wanted them to be successful, were interested in the project work, or believed in them. Some explained that other students in the program also cared about their successes. For example, a student said, "Especially my classmates, they're always saying 'you can do this,' and stuff like that. And the other people in Studio STEM, they want to succeed too. So they try to get other people to succeed." However, one student specifically noted that his teammate did not care about his success and another responded that she did not think her peers cared about other teams' successes. Researchers also observed that during one session, because of a competition between teams involving the successful completion of their solar cars, some students appeared unconcerned with the other teams' successes.

Table 3
Studio STEM elements, example motivating opportunities, and key MUSIC components affected

Studio STEM Elements	Example Motivating Opportunities	Key MUSIC Model Components Affected
Topic selection	▪ Opportunities to learn about STEM topics	▪ Usefulness
Presentations	▪ Opportunities to interest students in the topic and show the usefulness of it	▪ Interest, usefulness
Activity choices	▪ Opportunities to choose how to build the solar car	▪ Empowerment
Group interactions	• Opportunities to interact with other students in small groups	▪ Success, caring
Instructor support	• Opportunities for instructors to help students	• Success, caring

Discussion and Implications

The primary purpose of this study was to examine the ways in which Studio STEM affected middle school students' motivation and engagement in science and engineering activities. The high means on the questionnaire subscales and the high percentage of comments from the interviews and observations that were consistent with the MUSIC model (81.4%; see Tables 1 and 2) indicate that, overall, students were motivated to put forth effort and engage in the Studio STEM activities. These findings are also consistent with the students' self-reported effort. In the next two sections, we summarize the primary findings and offer implications for similar learning environments.

Motivating Opportunities

Based on our examination of data across our three data sources, we identified motivating opportunities that were provided to students in Studio STEM (see Table 3 for a summary and some examples). We found that these motivating opportunities triggered one or more of the MUSIC model components and, thus, were opportunities to motivate or demotivate students. Our data suggest that several elements of Studio STEM (more generally) and the Save the Seabirds curriculum (more specifically) were particularly motivating, which we describe with more detail in this section. We propose that the following examples offer

implications that can be modified by instructors in other student-centered and inquiry-based learning environments when intentionally designing instruction to motivate and engage science students.

Three primary strengths of the Studio STEM program were evident and are applicable to a variety of learning environments. The most frequently documented findings in both the interviews and observation data were (a) that the students perceived the facilitators and site leaders to be helpful, including their provision of informational and constructive feedback (e.g., facilitators helping students when they felt stuck, confused, or when something important was missed); (b) that the activities were hands-on such that the students could experiment on their own; and (c) that the students had choices in how to complete things. Although these three findings were the most prominent in both the interview and observation codes, other findings were also common in either the interviews *or* observation codes. These findings were organized in two ways: (a) prevalent codes in the observation data pertaining to general program features and (b) codes frequently noted in the interviews concerning specific activities or presentations.

Several codes related to overall program components were particularly prevalent in the observation data because they were integrated consistently into the Studio STEM program structure; thus, they were observed during multiple sessions. Of these, the majority pertains to the caring component of the MUSIC model, including the helpfulness and availability of the program facilitators and site leaders, who, in addition to helping students, clearly communicated a desire for students to be successful, trusted in the students' ideas and choices, and monitored the students' progress. In addition, many students highlighted the importance of their partners' support. Each of these speaks to a safe learning environment designed to foster positive relationships among the students, facilitators, and site leaders. Two additional codes were reported frequently and were only evident in the observation data: (a) the students frequently had control over a variety of materials and material choices during multiple activities, which could have contributed to their perceived empowerment; and (b) the facilitators and site leaders provided clear instructions and expectations, which likely supported the students' perceived success. These two components are consistent with previous research, which indicates that it is important to support students' success while encouraging their autonomy (Patall, Sylvester, & Han, 2014), especially when effectively implementing inquiry-based learning (Tai, Sadler, & Maltese, 2007).

Two activities and one lesson topic were prominent in the interviews. The majority of these codes relate to the interest component of the MUSIC model. The activities involved students directing the design and construction of two separate systems. One system was the solar car, which was the culminating project in the program in which students were provided a variety of materials (e.g., motors, solar panels, Legos) and options for design and construction, and worked on their cars during multiple sessions. Responses indicate that students' motivation was supported by the activity in general, the choices inherent in how to build the cars, and the outside support from facilitators, site leaders, and teammates. The second task involved teams designing and assembling a motor-powered system for raising a basket full of cubes using multiple materials (e.g., gears, Legos, solar panel). The level of autonomy built in to this activity was also highlighted in the findings. These two activities were similar in several respects: (a) students led the design and implementation of the systems following presentations of relevant background information in a cumulative manner over multiple sessions; (b) the provided materials offered many choices such that students not only had control over design but also which parts were used or abandoned (e.g., two options were provided for both the motors and solar panels); and (c) facilitators and site leaders were available to support the students' work and review the content material. Thus, although the two activities may not be applicable to other learning environments, these more general characteristics that we identified could be transferred to other environments. In addition to these two activities, multiple students agreed that learning about oil rigs and the environmental implications of oil spills throughout the program was particularly interesting. This suggests that connecting lessons and activities to real-world problems can positively affect motivation through the interest and usefulness components of the MUSIC model.

Missed Opportunities: Areas for Improvement

Codes relating to the usefulness component of the MUSIC model were the least common of the highest frequency codes. Thus, it is possible that the program could be improved by more often connecting the activities and presentations to students' goals (present and future), their lives at home, and the real world. However, it is possible that making only a few connections is necessary and that more connections would be redundant; this is a point that could be examined in future research. Another weakness predominant in the interview responses was that multiple students reported that their interest suffered during the direct instruction aspects of the program. Although

presentations may have been necessary for learning, our findings suggest that teacher-centered, lecture-based methods may not nurture interest as readily as other aspects of the program. Given that previous research suggests that direct instruction and prior knowledge are often essential to student success in the ill-structured environments typical of problem-based learning (e.g., Kirschner, Sweller, & Clark, 2006), we posit that instructors could attend to other components of the MUSIC model during more direct instruction (e.g., provide rationales to make it useful, incorporate meaningful choices) when lessons are less likely to trigger interest.

Conclusion

The results from each of the data sources were fairly consistent and demonstrated that Studio STEM motivated middle school students to engage in the science and engineering activities. However, we also documented some ways in which Studio STEM could be improved. Our findings indicate that it is possible to motivate students to engage with science and engineering concepts in a voluntary, afterschool program. Understanding the motivating opportunities we identified can help both formal and informal science educators better connect motivation theory to practice so that they can create motivating opportunities for students. Furthermore, this study provides a methodological example of how students' motivation can be examined during the context of authentic science and engineering instruction.

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Acknowledgment

This paper is based on research supported by the National Science Foundation under Grant No. DRL 1029756. Any opinions, findings, conclusions, and recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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A Research to Practice article based on this paper can be found alongside the electronic version at http://wileyonlinelibrary.com/journal/ssm.

Appendix

Example Items from the MUSIC Model of Academic Motivation Inventory—Middle School Version (Jones, 2012)

Note that these sample items were arranged randomly and students rated them on the following scale (see Jones, 2012, for the full version of the inventory):

1	2	3	4	5	6
Strongly Disagree	Disagree	Mostly Disagree	Mostly Agree	Agree	Strongly Agree

Empowerment

I had flexibility in what I was allowed to do during the Studio STEM activities.

Usefulness

The knowledge I gained in the Studio STEM activities is important for my future.

Success

I was capable of doing well at the Studio STEM activities.

Interest

The Studio STEM activities were interesting to me.

Caring

The [university] facilitator cared about how well I did in the Studio STEM activities.

Next Generation Science Standards: A National Mixed-Methods Study on Teacher Readiness

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Next Generation Science Standards (NGSS) science and engineering practices are ways of eliciting the reasoning and applying foundational ideas in science. As research has revealed barriers to states and schools adopting the NGSS, this mixed-methods study attempts to identify characteristics of professional development (PD) that will support NGSS adoption and to improve teacher readiness. In-service science teachers from across the nation were targeted for the survey and responses represented 38 states. Research questions included: How motivated and prepared are in-service 7–12 teachers to use NGSS science and engineering practices? What is the profile of 7–12 in-service teachers who are motivated and feel prepared to use NGSS science and engineering practices? The study revealed that teachers identified engineering most frequently as a PD need to improve their NGSS readiness. High school teachers rated themselves as more prepared than middle school and all teachers who use Modeling Instruction expressed higher NGSS readiness. These findings and their specificity contribute to current knowledge, and can be utilized by districts in selecting PD to support teachers in preparing to implement the NGSS successfully.

On April 9, 2013, the final draft of the Next Generation Science Standards (NGSS) was published. This document, the result of collaboration between Achieve, Inc. and 26 lead states, seeks to provide students nationwide with an internationally benchmarked education by articulating crosscutting and deeply conceptual science performance expectations (NGSS, 2013). Despite the final publication of NGSS and the commitment of lead states to adopt the standards, little exists in firm implementation strategies and timelines. Research has already identified barriers to NGSS implementation such as the limited instructional time currently devoted to science, the lack of physical resources for effective science education, and insufficient preparation of elementary teachers (Trygstad, Smith, Banilower, & Nelson, 2013). However, teacher preparedness is a concern at all levels as some current models of teaching (fact and lecture based) are incapable of satisfactorily addressing the mandates of NGSS, which emphasize conceptual and exploratory learning (Cooper, 2013). Thus, there is a national urgency to identify the kind of professional development (PD) that will best prepare teachers to meet the challenges of the NGSS. It may require a considerable investment of resources to develop the appropriate materials and tools to support both teachers and students (Wilson, 2013). We must realign the resources spent on PD with the demands teachers will face in an NGSS classroom, and also conduct the research required to learn from it.

The present study sought to meet the need for research on readiness and motivation of middle and high school in-service teachers to apply NGSS science and engineering practices in their classrooms. We also attempt to identify the characteristics of a teacher who feels well prepared to implement NGSS, to identify areas of content weakness and professional development needs, and to use the information we have learned from this survey's results to provide recommendations for teacher training as lead states begin the NGSS adoption process.

Literature Review

Not all teachers are receptive to educational innovations (Abrami, Poulsen, & Chambers, 2004). Some embrace the innovation with great enthusiasm and incorporate it into their teaching while others discard it and return to traditional teaching practices after only a few attempts (Lam, Cheng, & Choy, 2010). In order for teachers to persist in their efforts to adopt new strategies, they need to have the expectation that they will succeed (Abrami et al., 2004).

Academic Standards

To understand the relevance, potential implications, and likely trajectory of the NGSS implementation, it is first important to view academic standards within the more general historical context of standards-based educational reform. This history of academic standards as they are currently understood has its roots in a push for educational reform that began in the early 1980s, continued in strength through the 1990s, and continues to this day (Zuzovsky & Libman, 2006). This surge in the popularity of standards-based educational reform is often thought of as originating with the 1983 publication of *A Nation at Risk* (The National Commission on Excellence in Education, 1983) and the resulting nationwide panic over the state of

American education and the high school graduate's ability to function as a productive member in a national and international society (Vogler & Virtue, 2007). Problems of schooling were considered to be due to low accountability within the educational system. Standards made educational goals more transparent and directly indicate what is expected of stakeholders, namely teachers and students (Miskel & Ogawa, 1988). By 1989, curriculum standards were developed in math, and other subject areas soon followed suit (Delandshare & Petrosky, 2004).

Evolution of standards (state and national) in the STEM disciplines. NGSS is a set of science standards. Science and its fellow technology, engineering, and mathematics (STEM) disciplines are, and have been for a least a decade, the focus of tremendous concern and reform effort from educators nationwide (Dugger, 2010; Sanders, 2009). The reasons for this are varied. The concern that the United States is falling behind other nations of the world in STEM areas, and that this lack could potentially manifest as economic disaster in the future (Sanders, 2009) has resulted in an influx of federal funding for STEM education and research, and the encouragement of organizations (e.g., National Science Foundation, or NSF) to pursue this research (Dugger, 2010).

Over the past two decades, state science standards have been based on the 1996 *National Science Education Standards* (published by the National Research Council) and the 1993 *Benchmarks for Scientific Literacy* (Labov, 2006). Although these national documents do not represent standards adopted by all states, they aid in the development of state frameworks though this translation and adoption process has often proven difficult (Tanner & Allen, 2002). Subsequently, the No Child Left Behind Act (NCLB, 2002) was signed into law. According to the U.S. Department of Education (2002), this Act was meant to change the culture of American education by mandating achievement and results. These results are monitored via mandatory testing for all students enrolled in grades three through eight. NCLB requires that students be tested in reading language arts, mathematics, and science.

Although science is a subject for which NCLB mandates annual testing, the testing is not nationalized. NCLB gives states the responsibility to set standards, support classroom instruction, ensure qualified teachers, and create assessment tools to measure progress (Marx & Harris, 2006). As such, state-designed and implemented standards are generally related in content and form, though the degree of this interrelation is variable. It is possible that the need to create standards that can be measured by high-stakes testing, drives states toward producing standards that focus on facts rather than on difficult-to-measure skills such as deep thinking and conceptual understanding of the underlying processes of science and STEM subjects (Marx & Harris, 2006). Some claim that high-stakes testing at the secondary level prompts teachers to cover massive amounts of information, and so moving beyond an educational experience based in anything more that rote memorization is difficult (Vogler & Virtue, 2007).

NCLB and high-stakes testing have been criticized by both educators and educational researchers. One persistent criticism is that the high-stakes nature of these federally mandated tests promotes teaching to the test. (Cawelti, 2006; Flinders, 2005; Guilfoyle, 2006). Science standards are to some degree political documents, co-created by committees of individuals representing a broad spectrum of educational and scientific interest groups. A standards document produced in this way represents a group's best effort to find consensus about the essential concepts to be learned within scientific subdisciplines. However, these standards cannot ensure that the concepts will receive similar treatment in all classrooms.

The developmental trajectory of NGSS. In the summer of 2011, a writing team of 41 individuals began work on the first draft of the NGSS. As the effort was intended to be a collaborative effort of various stakeholders, the document was released for public review multiple times, and the writers were charged with being responsive to the feedback these drafts received. On April 9, 2013, the finalized NGSS document was released.

NGSS describe what all students should know and be able to do by the time they graduate from high school. NGSS are based on learning progressions of core ideas in the discipline, concepts that cut across disciplines and practices that will allow students to use their disciplinary knowledge in meaningful ways. An important advance from earlier standards from the National Research Council (NRC, 1996), NGSS Science and Engineering Practices are clearly identified not as separate learning goals that define what students should know about the process of science, but rather as ways of identifying the reasoning behind, discourse about, and application of the core ideas in science (Reiser, Berland, & Kenyon, 2012).

The science and engineering practices outlined in the NGSS are: asking questions and defining problems, developing and using models, planning and carrying out investigations, analyzing and interpreting data, using mathematics and computational thinking, constructing explanations and designing solutions, engaging in argument from evidence, and obtaining, evaluating, and communicating information (Achieve, Inc., 2013).

The process of creating the NGSS was driven by 26 lead states. These states contributed resources and support to the development process, and are expected to be trailblazers in the adoption and implementation of the NGSS. The choice to implement curricula and the form these curricula will take is consequently at the discretion of individual states.

NGSS and Modeling Instruction

One cornerstone of NGSS (Achieve, Inc., 2013) is the use of eight core science and engineering practices, which are identified above. These practices are at the foundation of Modeling Instruction, a research-based pedagogy for science education, developed in the 1980s.

Modeling Instruction integrates a student-centered teaching method with a model-centered curriculum (Hestenes, 1996; Jackson, Dukerich, & Hestenes, 2008). It applies structured inquiry techniques to teaching basic skills in mathematical modeling, proportional reasoning, quantitative estimation, and data analysis, which contribute to the development of critical thinking, including the ability to formulate hypotheses and evaluate them with rational argument and evidence.

Modeling pedagogy has three components: the models, the Modeling Cycle, and classroom discourse management (Hestenes, 1996). An understanding of these components is the pedagogical content knowledge (Shulman, 1986) needed for successful classroom implementation. A model is a representation of structure—a conceptual representation of a real thing (Hestenes, 1987). According to Johnson-Laird (1996), mental models have a structure that corresponds to the structure of what they represent. He defines perception as the transformation of sensory information into a mental model, and defines thinking as the manipulation of mental models. The models around which learning is centered in modeling are fundamental relationships among quantities that form the content core of a discipline (e.g., physics), and these models are developed by students into tools for making sense of physical reality—for making predictions and answering questions.

Modeling is an activity. Based on Karplus' Learning Cycle (Karplus, 1977), the Modeling Cycle (Hestenes, 1987) is a three-phase process: (a) model construction, which takes place in the context of a paradigm lab that uncovers a relationship between two physical quantities at the beginning of each instructional unit, (b) model validation, in which the student refines the basic model that he or she has constructed by testing it in different initial conditions, and (c) model deployment, in which the student uses the model to solve problems from a variety of contexts. This is analogous to the model-of-model for progression (Streefland, 1985; Treffers, 1987; Van den Heuvel-Panhuzen, 2003) described by Dutch Realistic Mathematics Education researchers who characterize models as bridging objects from informal to formal reasoning.

Others have contributed to current understanding of how students develop and use models in K–12 classrooms. Modeling research has focused on argumentation in science education (Bottcher & Meisert, 2011; Passmore & Svoboda, 2012), the role of models and analogies in science education (Coll, France, & Taylor, 2005), software scaffolds supporting modeling practices (Fretz et al., 2002), model-based inquiry (Passmore, Stewart, & Cartier, 2009), integrating conscious and intuitive knowledge (Cheng & Brown, 2010), and constructing and revising models in the science classroom (Krajcik & Merritt, 2012). Numerous researchers investigating modeling nationally and internationally have influenced the conceptualization of modeling articulated in NGSS (Schwarz et al., 2009; Windschitl, Thompson, & Braaten, 2008).

Teachers learn Modeling Instruction by participating in a Modeling Workshop—an intensive, three-week 90-hour immersion experience. Teachers participate in laboratory investigations and activities, designing experiments, collecting, analyzing, interpreting data, and engaging in classroom discourse to achieve collective sense-making. It is only by active participation in the discourse that characterizes the Modeling learning that a teacher can become an effective manager of modeling discourse in his or her own classroom.

The Modeling Instruction Program has been in existence since 1990. From its initial beginnings in college and high school physics, it has spread across the science disciplines into chemistry, biology, physical science, and middle school (integrated) science. Quantitative evidence supporting the impact of Modeling Workshops has been established through study undertaken as part of the Modeling Workshop Project evaluation and the U.S. Department of Education has identified Modeling Instruction as one of two Exemplary K–12 Science Programs.

Study Overview

This study examines in-service teacher motivation to adopt NGSS science and engineering (S&E) practices and their feelings of readiness to implement these practices in their classrooms. We attempt to discern the characteristics of teachers who feel well prepared to implement NGSS practices and could potentially become mentors for their peers in the NGSS adoption process. In particular, we explore the link between those who identify themselves as

"Modelers" (i.e., practitioners of the Modeling Method of Instruction and NGSS receptiveness and readiness).

Survey data for a pilot study were collected from a group of 45 middle and high school science teachers from four suburban school districts who were participating in a Math Science Partnership PD program to develop skill in using NGSS science and engineering practices. Data from their responses revealed that these science teachers were motivated to use NGSS science and engineering practices, particularly those trained in the use of Modeling Instruction. The pilot study instrument served as the foundation for the larger national online survey developed for administration in March and April of 2013.

Method

Research Design

This study employed a mixed-method approach and thus, the investigator collected, analyzed, and drew inferences from both quantitative and qualitative data in a single study. It involved the assumption that the use of quantitative and qualitative approaches in combination provides greater understanding of the research problem than either approach alone (Creswell & Plano Clark, 2011; Johnson, Onwuegbuzie, & Turner, 2007). The survey had several open-ended questions and comment boxes to enable teachers to provide rich texture around the survey responses. Teachers could further discuss NGSS concerns (e.g., inadequate training) or identify additional support and resources needed for implementation.

The research design included both quantitative and qualitative methods and employed analysis of variance (ANOVA) to determine differences between groups and qualitative analysis to code, categorize, and analyze teacher comments. The assumptions of homogeneity of variance, normality, and independence were tested and met. The survey used a 5-point Likert scale to determine the extent to which teachers felt they needed professional development to prepare for NGSS adoption and to elicit current levels of motivation and perceived readiness to use NGSS science and engineering practices. A test for internal consistency was conducted showing a Cronbach's alpha of .85. This is commonly used as an estimate of the reliability of a psychometric test. An open-ended response section was provided for teachers to volunteer comments with respect to survey items. Research questions that guided the study included:

1. How motivated are in-service 7–12 teachers to use NGSS S&E practices?
    a. What are the differences between middle school and high school teachers?
2. How well prepared do 7–12 teachers feel to use NGSS S&E practices?
    a. What are the differences between middle and high school teachers?
3. Do teachers trained in the use of Modeling Instruction feel more motivated and prepared to use NGSS S&E practices?

The survey collected information on school size and type (public, private, or charter), teacher interest in professional development and the type of PD that appealed to them (e.g., STEM and NGSS training), and sociodemographic characteristics like age, years of teaching, subjects taught, and grade levels taught. Based on pilot study findings, it was hypothesized that years of teaching, types of courses taught, and a prior training in and teaching Modeling Instruction would predict perceived readiness for NGSS.

Participants and Context

In-service teachers from across the nation were invited to complete the survey. These individuals were employed in public, private, and charter schools and represent a national pool of teachers who teach primarily science in middle school and high school: physics or physical science, chemistry, and biology. Teachers who subscribed to science listservs were sent a link to the NGSS Readiness Survey in March of 2013. The survey received 710 teacher responses from across the United States representing 38 states.

Quantitative Data

In order to answer the first research question (How motivated are in-service 7–12 teachers to use NGSS science and engineering practices?), a bank of survey questions was provided that included the eight NGSS S&E practices. To answer the second question (How prepared do 7–12 teachers feel to use NGSS S&E practices?), teachers rated their perceived success in applying the eight practices in the classroom. To answer the third research question (Do teachers trained in the use of Modeling Instruction feel more motivated and prepared to use NGSS S&E practices?), we used statistical analyses to look for group differences.

Data analysis. A 2×2 factorial ANOVA was used to determine specific NGSS practice areas in which Modelers felt more NGSS ready. When there was a statistically reliable overall difference in NGSS readiness scores (for Modeling or grade level), we used a two-tailed, independent samples *t*-test to identify the direction of this difference. All tests had an alpha level of .05.

Qualitative Data

Teachers were given the opportunity to comment on their NGSS readiness and motivation in a comment box.

Teachers could express any concerns in this area, and as a result, areas of content weakness emerged without prompting. The researcher used the constant comparative method (Glaser & Strauss, 1967) as a conceptualizing method on the first level of abstraction. Teacher comments (open-ended comments) were conceptualized line by line. The initial phase involved conceptualizing all the incidents in the data. The researcher compared data and continually modified and sharpened the growing theory at the same time. Notes were compared to find differences and consistencies between codes (e.g., similarity in meanings), which helped reveal categories. Data were analyzed using a three-step process: data reduction, data display, and conclusion drawing and verification (Miles & Huberman, 1994). Data reduction helped sort, focus, and condense excerpts, which helped organize the data to develop conclusions. Data display enabled review of the reduced data so that conclusions could be drawn. Teachers' excerpts formed the basis for identifying categories, themes, and assertions.

Quantitative Results

Overall, demographic data for the 710 teachers who responded to the NGSS national readiness assessment revealed that about one third held a bachelor's degree (27%), 68% had a master's degree, and 5% had a doctorate degree. Demographic information is shown in Table 1.

The majority of respondents taught physics (32%), followed by "science" (23.5%) (presumably an integrated or general science course), chemistry (20.4%), biology (18.8%), mathematics (2.7%), earth science (2.4%), and physical science (0.2%).

NGSS Teacher Motivation: Middle School and High School Differences

To answer the first research question, "How motivated are in-service 7–12 teachers to use NGSS science and engineering practices"? (and the sub-question, "What are the differences between middle school and high school teachers?"), the study employed a 5-point Likert scale. The scale used a range of 5 = "Highly motivated" to 1 = "Not motivated." High school teachers were reported a higher degree of motivation to use all eight NGSS science and engineering practices than middle school teachers. Results are shown in Table 2.

NGSS Readiness to Use Science and Engineering Practices: Teacher Differences

To answer the second research question, the survey included a 5-point Likert scale to determine NGSS readiness by asking teachers to rate their expectation of success in implementing NGSS science and engineering practices (5 = "Highly certain of success" to 1 = "Cannot expect success"). High school teachers' responses indicated they felt more prepared to implement NGSS science and engineering practices than middle school teachers (Table 3).

Table 1
Demographic Data for Survey Respondents

Sex	
Male	43%
Female	57%
Degree	
Bachelor's	27%
Master's	68%
Doctorate	5%
Certification	
Baccalaureate	49%
Post-baccalaureate	47%
None	4%
School Type	
Public	86%
Private	10%
Charter	4%
School Size	
Small	6%
Medium	20%
Large	26%
Very Large	48%
Teaching Assignment	
Physics	32%
Chemistry	20.4%
Biology	18.8%
Other Science	2.6%
Math	2.7%
Science (Middle School)	23.5%
Trained in Modeling Instruction	
Yes	51%
No	49%

Note. Total sample size (710 teachers): 51% Modelers (362 teachers), 49% non-Modelers (348 teachers).

NGSS Readiness: an Examination of Modelers and Non-Modelers

Of the respondents, 51% (362 teachers) indicated they used the Modeling Method of Instruction (indicated "Yes" on the survey), while 49% were non-Modelers (indicated "No"). The middle school Modelers had been teaching the same number of years ($M = 16$, $SD = .88$), as high school Modelers ($M = 15.82$, $SD = .89$) and practiced Modeling Instruction in the classroom for the same number of years ($M = 5.8$, $SD = .58$) as high school Modelers ($M = 6.04$, SD

Table 2
NGSS Eight Practices and Motivation: Middle School and High School Teacher Differences

	Middle School Mean (*SD*)	High School Mean (*SD*)
Motivation		
Asking questions and defining problems	4.28 (.717)	4.54* (.647)
Developing and using models	4.32 (.747)	4.57* (.617)
Planning and carrying out investigations	4.24 (.870)	4.44* (.727)
Analyzing and interpreting data	4.31 (.818)	4.62* (.600)
Using math and computational thinking	4.17 (.854)	4.53* (.686)
Constructing explanations and designing	3.90 (.881)	4.29* (.833)
Solutions		
Engaging in argument from evidence	4.23 (.807)	4.50* (.733)
Obtaining, evaluating, communicating information	4.39 (.720)	4.54* (.614)

* $P < .05$. Total sample size (710 teachers).

Table 3
NGSS Practices and Readiness: Middle and High School Teacher Differences

	Middle School Mean (*SD*)	High School Mean (*SD*)
Teachers would have success in:		
Asking questions and defining problems	4.09 (.763)	4.38* (.684)
Developing and using models	4.05 (.869)	4.30* (.732)
Planning and carrying out investigations	3.99 (.867)	4.21* (.791)
Analyzing and interpreting data	4.10 (.831)	4.45* (.658)
Using mathematics and computational thinking	3.90 (.859)	4.31* (.771)
Constructing explanations and designing solutions	3.53 (.936)	3.98* (.901)
Engaging in argument from evidence	3.99 (.874)	4.34* (.787)
Obtaining, evaluating, and communicating information	4.19 (.818)	4.42* (.684)

Note. Total respondents (710 teachers). Degree of predicted success (5 = highly certain to 1 = cannot expect success).
* $P < .01$.

= .68). Middle school Modelers had participated in an average of 64 hours of Modeling PD; the average high school Modeler had completed 117 hours of Modeling PD as seen in Table 4.

Training in modeling instruction. There are a variety of professional development experiences that provide

Table 4
Modeler Demographics

	Middle School Modelers Mean	High School Modelers Mean
Hours/Modeling workshops	64	117
Years using modeling instruction	5.8	6
Years of teaching	16	15.87

Note. Modeling respondents (362 teachers).

teachers with training in the Modeling Method of Instruction, from one hour after school sessions, or four to eight-hour sessions at professional conferences, to multi-week Modeling Workshops. Full Modeling Workshops are typically 60–90 hours in length (two to three weeks). This sample of Modelers' median of 90 hours indicates that the typical respondent attended a 90-hour workshop. While the high school Modelers, on average, attended a three-week workshop, the middle school Modelers attended a two-week workshop.

NGSS Motivation: Modelers and Non-Modelers

To answer the third research question, "Do teachers trained in the use of Modeling Instruction feel more motivated and prepared to use NGSS science and engineering practices?" Modelers expressed more motivation to use NGSS S&E practices than non-Modelers, and the difference was significant for all items ($P < .01$) as seen in Table 5.

NGSS Performance: Modelers and Non-Modelers

Those who use Modeling Instruction rated themselves as better prepared to utilize NGSS science and engineering practices than non-Modelers, and the differences were significant for all eight NGSS practices ($P < .05$). Teacher perceptions of NGSS readiness are shown in Table 6.

Modelers rated themselves as better prepared to implement NGSS science and engineering practices, including "Constructing explanations for science and designing solutions for engineering" reflected in the means for Modelers ($M = 4.10$, $SD = .866$) and non-Modelers ($M = 3.84$, $SD = .954$). In addition to probing for readiness to utilize the NGSS practices, the survey included one item that specifically elicited readiness to incorporate engineering problem solving into science instruction. Modelers felt more prepared for "Effectively using engineering problems to help students understand science concepts" than the non-Modelers, and the difference was significant.

Grade Levels and Modeling: Differences Between Groups

Results from the ANOVA showed that there were no statistically reliable interactions between Modeling and

Table 5
How Motivated Are Teachers Who Model Versus Those Who Don't Model?

	Modelers Mean (*SD*)	Non-Modelers Mean (*SD*)
I am motivated to:		
Ask questions and define problems	4.58 (0.616)	4.38* (0.692)
Develop and use models	4.69 (0.545)	4.14* (0.744)
Plan and carry out investigations	4.60 (0.613)	4.29* (0.824)
Analyze and interpret data	4.67 (0.567)	4.35* (0.699)
Use math and computational thinking	4.51 (0.692)	4.27* (0.814)
Construct explanations, design solutions	4.38 (0.780)	4.09* (0.893)
Engage in argument from evidence	4.57 (0.672)	4.32* (0.797)
Obtain, evaluate, and communicate information	4.59 (0.585)	4.41* (0.682)

Note. Total respondents (710 teachers): 51% Modelers (362 teachers), 49% non-Modelers (348 teachers).
* $P < .01$.

Table 6
Success in NGSS Practices: Modelers Versus Non-Modelers

	Modelers Mean (*SD*)	Non-Modelers Mean (*SD*)
Teachers would have success in:		
Asking questions and defining problems	4.38 (0.691)	4.26* (0.752)
Developing and using models	4.37 (0.723)	4.11* (0.794)
Planning and carrying out investigations	4.24 (0.794)	4.09* (0.823)
Analyzing and interpreting data	4.47 (0.653)	4.27* (0.756)
Using math and computational thinking	4.38 (0.722)	3.90* (0.039)
Constructing explanations for science and designing solutions for engineering	4.10 (0.866)	3.84* (0.954)
Engaging in argument from evidence	4.38 (0.791)	4.11* (0.837)
Obtaining, evaluating, and communicating information	4.44 (0.682)	4.30* (0.752)
Effectively using engineering problems to help understand science concepts	3.65 (0.969)	3.47* (1.018)

Note. Degree of predicted success (5 = highly certain to 1 = cannot expect success). Total sample size (710 teachers): 51% Modelers (362 teachers), 49% non-Modelers (348 teachers).
* $P < .05$.

grade level for any of the eight selected NGSS practices. That is, the effect of Modeling does not depend on grade level. Thus, we would expect to find reliably higher means for Modelers in both middle and high school teachers. The researchers classified teachers who indicated that they taught in grades seven and eight as teaching at the "middle school" level and those teaching in grades nine, ten, eleven, and twelve as teaching at the "high school" level.

Modelers in middle school and in high school also rated themselves as more "prepared" to implement the NGSS science and engineering practices in five of the eight practices: Developing and using models (NGSS S&E #2), analyzing and interpreting data (NGSS S&E #4), using mathematics and computational thinking (NGSS S&E 5), constructing explanations and designing solutions (NGSS S&E #6), and engaging in argument from evidence (NGSS S&E #7). Modelers from middle school and high school had similar results in developing and using models and using math and computational thinking. Grade level differences are shown in Table 7.

In order, by NGSS practices: High school Modelers rated their NGSS readiness reliably higher ($M = 4.40$, $SD = .73$) than did high school non-Modelers ($M = 4.20$, $SD = .72$) in developing and using models ($P < .001$). High school Modelers felt better prepared ($M = 4.51$, $SD = .64$) than did high school non-Modelers ($M = 4.36$, $SD = .67$) in analyzing and interpreting data ($P = .01$). High school Modelers also had higher scores ($M = 4.42$, $SD = .71$) than did non-Modelers ($M = 4.17$, $SD = .83$) in using mathematics and computational thinking ($P < .001$). Finally, High school Modelers also rated themselves as more prepared in constructing explanations and designing solutions ($P = .01$) than non-Modelers.

Qualitative Results

Elements Needed to Facilitate NGSS Adoption

Qualitative comments indicate that although most teachers are positive about NGSS, they are anxious about inadequate training, limited instructional time, and lack of resources, all barriers to implementation. Teachers' comments in this study echoed impediments previously identified in a study of elementary teachers, such as insufficient preparation, limited instructional time devoted to science, and the lack of physical resources for effective science education (Trygstad et al., 2013). In addition to fears about the implementation, the comments (commenters' names have been replaced by pseudonyms in the sections below) also revealed that many teachers considered the standards to be too complex in some case exceeding the knowledge and training of the educators who would be expected to teach the content mandated.

Professional development needed. Although at first glance it appears that most teachers rate themselves as reasonably competent to incorporate NGSS S&E practices into their teaching, the accompanying comments by

Table 7
Middle and High School: Modelers and Non-Modeler Differences

Group	High School Non-Modeler Mean (*SD*)	High School Modeler Mean (*SD*)	Middle School Non-Modeler Mean (*SD*)	Middle School Modeler Mean (*SD*)
Asking questions and defining problems	4.34 (.68)	4.41 (.69)	4.0 (.79)	4.1 (.70)
Developing and using models	4.20 (.72)	4.40 (.73)***	3.40 (.93)	4.27 (.67)*
Planning and carrying out experiments	4.14 (.77)	4.26 (.80)	3.95 (.92)	4.10 (.74)
Analyzing and interpreting data	4.36 (.67)	4.51 (.64)**	4.10 (.88)	4.20 (.68)
Using mathematics and computational thinking	4.17 (.83)	4.42 (.71)***	3.84 (.90)	4.15 (.73)*
Constructing explanations and designing solutions	3.92 (.93)	4.20 (.88)**	3.67 (.99)	3.95 (.74)
Engaging in argument from evidence	4.31 (.77)	4.37 (.80)	3.92 (.91)	4.23 (.73)*
Obtaining, evaluating, and communicating information	4.36 (.68)	4.46 (.69)	4.12 (.88)	4.37 (.62)

Note. Degree of predicted success (5 = highly certain to 1 = cannot expect success). Total sample size (710 teachers): 51% Modelers (362 teachers), 49% non-Modelers (348 teachers).
* $P < .05$; ** $P < .01$; *** $P < .001$.

respondents indicate there is concern and in some cases outright anxiety about expectations with respect to their use of and success with S&E practices. Teachers see a need for PD at both middle school and high school levels to facilitate successful NGSS adoption. The majority (84.9%) of teachers in this national sample are interested in pursuing future NGSS PD, but most indicated they would do this only if their school or district was willing to pay for it (70%). Teachers indentified the content focus for PD needed to improve NGSS readiness as follows: engineering (65.6%), technology (50%), science (45.5%), and mathematics (26.2%). Engineering emerged as the content area of greatest need, which is reflected in this excerpt, "I have only a loose grasp on the engineering and design part of the standards and am in desperate need of a concise overview of what they are and how to incorporate them into my teaching" (C. Valdez, survey response, April 13, 2013). Another teacher stated, "The engineering practices in the NGSS standards intrigue me, but I'm a science teacher, not an engineer. I do build projects in my classes to relate the physics to the practical aspects of engineering, but I have no training in this" (S. Rymes, survey response, April 15, 2913). As noted by T. Myers (survey response, April 28, 2013), "As a whole, most teachers will be less comfortable with the science and engineering practices than the disciplinary core ideas. There will be teacher misconceptions on what the performance expectations really are. Without profession development and supports, teachers will not be effective." A final comment on the critical need for training showed a middle school teacher's concern, "I think NGSS is a good idea but if middle-school teachers are not trained, it will fail. Current standardized testing pulls the curriculum in different path. I see these two as opposing forces" (A. Boss, survey response, April 27, 2013).

More instructional time and resources needed. Open-ended survey feedback revealed other concerns about NGSS implementation: limited instructional time and resources. A large response rate from middle school teachers (68%) indicated that teachers perceived time as a barrier to successful NGSS implementation. Teachers recognized that cross-cutting concepts were important but realized that reform is needed to allocate more instructional time. One participant (J. Mendez, survey response, April 16, 2013) echoed this sentiment, "More time is needed to teach a course using the inquiry method and NGSS will require more time and resources." Another teacher talked about adding engineering to his instruction, which will also require more time and materials, "I hope adding engineering doesn't mean we must always build something. Engineering practices can be met by applying knowledge and skills to real world scenarios. Building and design will cost a lot of money and take up a lot of my current class time" (J. Johnson, survey response, April 10, 2013). The lack of resources and time represent a significant impediment to the NGSS as noted in prior research; in addition to the new standards, teachers will have to contend with not having the necessary facilities, equipment, materials, or time for science teaching (Trygstad et al., 2013).

A theme running throughout the comments reinforced the notion that teachers lacked an engineering background, and many suggested they needed additional training, "I like that the focus has been shifted from 'learning' science to 'doing' science. Yet, most of us that will be implementing these standards have no engineering background or training and are ill prepared to effectively implement engineering practices" (J. Beck, survey response, April 4, 2013).

Modeling instruction well aligned with NGSS. Teacher comments linked NGSS with Modeling Instruction, as one participant indicated, "Modeling is well aligned with the skills and practices outlined by NGSS" (J. Smith, survey response, April 29, 2013). Another teacher echoed this alignment, reflected in this excerpt, "I'm excited about the NGSS. I am a teacher using the modeling method so I am comfortable with models and scientific thinking in my classrooms" (A. Banks, survey response, April 17, 2013). Comments linking NGSS to Modeling Instruction were frequent in the subset of Modeling respondents, as one noted, "The linkage between NGSS and Modeling is obvious for those who practice Modeling.

Discussion

This study sought to determine how prepared and motivated middle and high school teachers are to adopt and use NGSS S&E practices in their classrooms. Research suggests that there are likely to be significant challenges to overcome for states, districts, and schools that adopt NGSS (Trygstad et al., 2013). Three barriers that have already been identified by prior research are: the need for time, resources, and training. In addition to concerns about limited school resources and instructional time (e.g., the difference between how science is currently taught and what NGSS will mandate), the third area of concern is teacher preparation (Cooper, 2013; Trygstad et al., 2013), which has been examined at both the middle and high school levels in this study. We found that high school teachers who have completed an average of 90 hours of professional development in Modeling Instruction (the typical three-week workshop) feel significantly more motivated and better prepared for NGSS than high school teachers who are non-Modelers. Middle school teachers, with an average of 64 hours of professional development in Modeling Instruction, felt better prepared in a number of NGSS practice areas than non-Modeler middle school teachers. Both high school and middle school teachers identified a need for preparation in engineering content.

Perceived Success in Utilizing NGSS Science and Engineering Practices

Current science teaching practices often emphasize the memorization of facts, yet NGSS emphasizes the primacy of the active construction by students of conceptual knowledge by "doing science" via science and engineering practices. Modeling Instruction shifts the paradigm of how science is taught to a pedagogy that is well aligned with NGSS S&E practices. Teachers trained in Modeling Instruction feel better prepared and more likely to succeed in implementing these practices in their classrooms. Modelers say that they are already routinely incorporating S&E practices into their daily classroom activities.

Limitations

This survey was distributed via a collection of local and national listservs to which middle and high science teachers subscribe. Respondents were self-selected as there was no incentive for survey completion. Therefore, these survey results are generalizable to the population of teachers who would routinely read such a list—teachers who care enough about their teaching and learning to look to their peers for ways to improve their classroom practice.

Implications

Modelers express more motivation and readiness to use NGSS S&E practices. What might this mean to the schools and districts they serve? This teacher community offers a profile of well-prepared, confident teachers who could become leaders in NGSS teacher professional development. In addition, they could be enlisted as peer mentors in schools and districts to help with the transition to the new standards.

As NGSS move toward large-scale adoption and implementation, it is critical that educational leaders nationwide understand what these standards and the changes they portend will mean for the teachers who must work with them. To this end, our study attempts to identify factors affecting implementation and teacher readiness, particularly in the area of science and engineering practices. Our results support and build upon prior research on elementary teachers, adding to the extant literature on NGSS readiness. Similar to the findings of Trygstad et al. (2013), our data indicate a need for focused professional development for both high school and middle school teachers. Among other things, we have found that teachers are concerned about receiving additional training and education in engineering. Teachers also perceived time as a barrier to successful NGSS implementation. Teachers recognized that cross-cutting concepts were important but realized that reform is needed to allocate more instructional time.

We have found significant links between teachers' use of Modeling Instruction and their confidence in using NGSS science and engineering practices. Teachers with training in Modeling Instruction feel more motivated and better prepared to implement NGSS S&E practices in their classrooms. In fact, they are already doing so. Seventy Modeling Workshops held nationwide each summer serve 1,000 physics, chemistry, biology, and physical science teachers at 20–25 host institutions (universities and school districts). This professional development network is a

resource for middle school and high school teacher professional development in NGSS S&E practices that is already in place nationwide.

The Modeling teacher community numbers over 7,000 at present. Two hundred Modeling teachers have received training to lead Modeling Workshops. Thus, the excess capacity already exists in the Modeling teacher community to double the number of Modeling Workshops that serve secondary science teachers each summer.

The findings of this study indicate that in-service teachers believe they need training to adequately implement NGSS S&E practices. Those responsible for ensuring successful implementation need to heed this call by teachers.

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Authors' Notes

Keywords: science/science education, professional development, teacher education, curriculum, curriculum development, mixed-methods study.

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PROBLEMS section

Ted Eisenberg, Section Editor

This section of the Journal offers readers an opportunity to exchange interesting mathematical problems and solutions. Please send them to Ted Eisenberg, Department of Mathematics, Ben-Gurion University, Beer-Sheva, Israel or fax to 972-86-477-648. Questions concerning proposals and/or solutions can be sent via e-mail to eisenbt@013.net. Solutions to previously stated problems can be seen at http://www.ssma.org/publications.

Solutions to the problems stated in this issue should be posted before February 15, 2016

▪ **5373:** *Proposed by Kenneth Korbin, New York, NY*

Given the equation $\dfrac{2\sqrt{2}}{\sqrt{343-147\sqrt{5}}-\sqrt{315-135\sqrt{5}}}=\sqrt{x+y\sqrt{5}}$.

Find positive integers x and y.

▪ **5374:** *Proposed by Roger Izard, Dallas, TX*

In a certain triangle, three circles are tangent to the incircle, and all of these circles are tangent to two sides of the triangle. Derive a formula which gives the radius of the incircle in terms of the radii of these three circles.

▪ **5375:** *Proposed by Michael Brozinsky, Central Islip, NY*

Determine whether or not there exist nonzero constants a and b such that the conic whose polar equation is

$$r=\sqrt{\frac{a}{\sin(2\theta)-b\cos(2\theta)}}$$

has a rational eccentricity.

▪ **5376:** *Proposed by Arkady Alt, San Jose, CA*

Let $a_1, a_2, \ldots, a_n, b_1, b_2, \ldots, b_n$ be positive real numbers such that $a_1 < a_2 < \ldots < a_n$ and $a_n \in (b_i, b_{i+1})$, $i = 1, 2, \ldots, n-1$. Let

$$F(x)=\frac{(x-b_1)(x-b_2)\ldots(x-b_n)}{(x-a_1)(x-a_2)\ldots(x-a_n)}.$$

Prove that $F'(x) < 0$ for any $x \in Dom(F)$.

▪ **5377:** *Proposed by José Luis Díaz-Barrero, Barcelona Tech, Barcelona, Spain*

Show that if A, B, C are the measures of the angles of any triangle ABC and a, b, c the measures of the length of its sides, then holds

$$\prod_{cyclic}\sin^{1/3}(A-B)\le\sum_{cyclic}\frac{a^2+b^2}{3ab}\sin(A-B).$$

▪ **5378:** *Proposed by Ovidiu Furdui, Technical University of Cluj-Napoca, Cluj-Napoca, Romania*

Let $k \ge 1$ be an integer. Calculate

$$\int_0^\infty \ln^k\left(\frac{e^x+1}{e^x-1}\right)dx.$$

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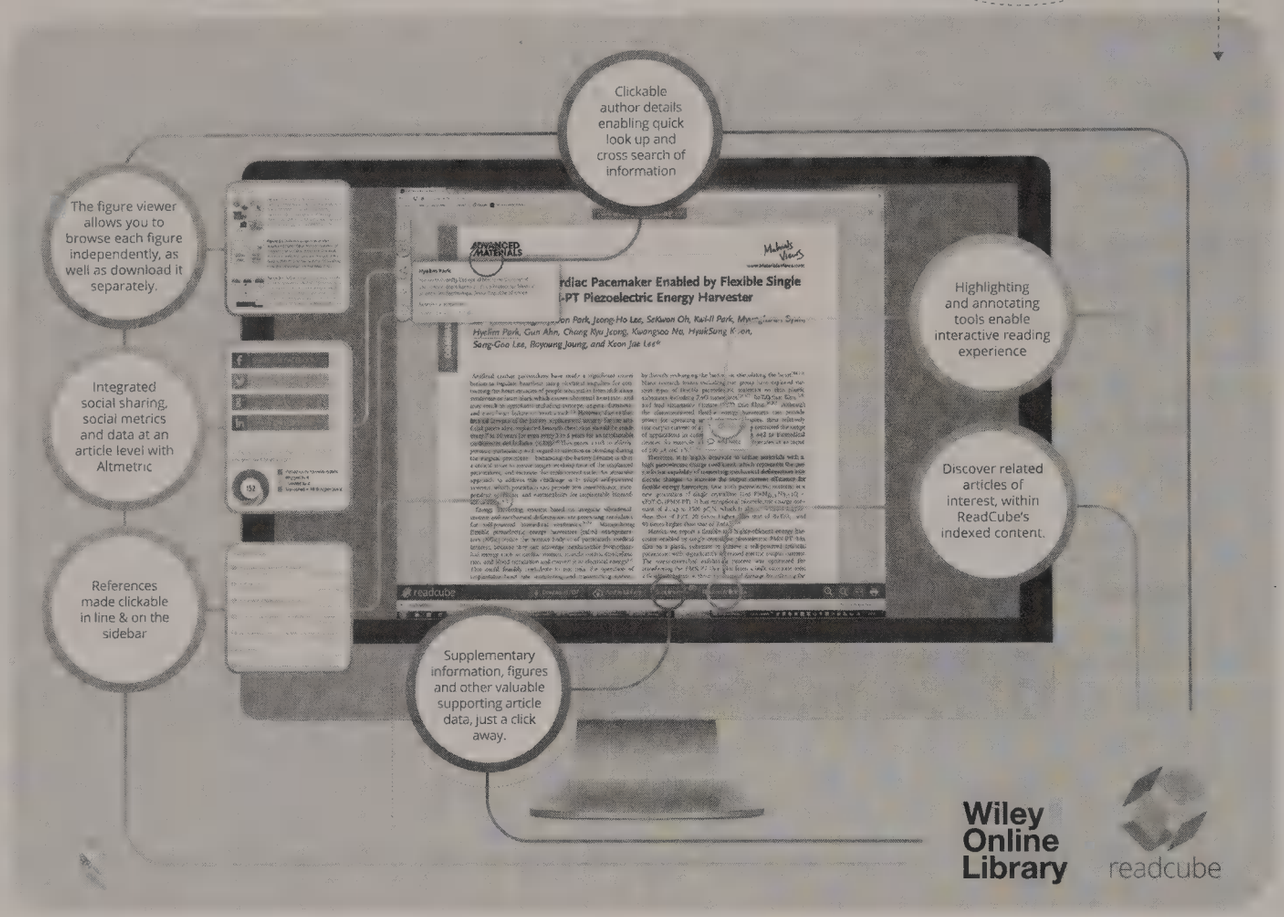
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Purdue University
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